STUDIES ON THE SHAPE OF DRIVEN PILES FROM MODEL TESTS

by

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DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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STUDIES ON THE SHAPE OF DRIVEN PILES FROM MODEL TESTS

A Thesis Submitted
In Partial Fulfilment of the Requirements
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by

WAQAR ASRAR

to the

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CERTIFICATE

Certified that this work on "STUDIES ON THE SHAPE OF DRIVEN PILES FROM MODEL TESTS" has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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ACKNOWLEDGEMENTS

Sincere gratitude is due to Dr. M.R. Madhav for initiating me to this problem. His help in getting this work done deserves much more than the expression Thank You.

I would like to express my sincere thanks to Mr. K.V. Lakshmidhar, Mr. R.P. Trivedi and Mr. Gulabchand- all of the Soil Mechanics Laboratory.

Thanks are due to Mr. S.C. Goel and Mr. Siddiqui of the Structures Lab. who helped the author in carrying out the experiments.

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A whole lot of friends deserve a pile of thanks notably M/s. K.S. Ramakrishna, P.P. Vitkar, E.S.Reddy, Mohammad Salim, Omar S.Al - Ayed, Mohd. Rafat, A.K. Mody, D.G. Roy, S. Agrawala and Mohammad Nauman.

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WAQAR ASRAR

LIST OF SYMBOLS

b	-	width of section
d	-	smaller width of section
ϵ_x	-	strain due to bending
E	-	modulus of elasticity
I	-	area moment of inertia
L	-	length
M	-	bending moment
v	-	deflection at point x
x	-	point on the neutral axis of the pile
y	-	normal distance from the neutral axis to point at which strain is being measured
c	-	maximum deflection of the pile

ABSTRACT

1.	Name of the Student	:	WAQAR ASRAR
2.	Programme	:	M. Tech.
3.	Department	:	Civil Engineering
4.	Title of Thesis	:	Studies on the Shape of Driven Piles From Model Tests
5.	Supervisor	:	Dr. M.R. Madhav

Piles seldom can be driven "straight". Most of the work on different aspects of pile behaviour assumes ideally straight piles.

A relatively small amount of work has been done on bent piles. It has been shown that the capacity of a pile decreases once the pile is not "straight". The shape of the pile has a marked effect on its behaviour.

Only a few tests have been made to get the pile shape in the field. No model studies have been made to get the shape of driven piles.

In this thesis tests performed on model piles were reported. The actual pile shape has been measured and plotted for various L/d ratios. Behaviour of driven piles under axial and lateral load has been studied. Also the ultimate pull-out resistance of the pile has been measured.

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CHAPTER I

INTRODUCTION

Every structure is as safe as its foundation. For large projects nearly 15-20 % of the civil construction cost is pumped into the ground in the form of foundations. Type of foundation depends upon the subsoil, the type of structure, the total load, permissible settlement, etc. Higher the building, deeper one goes for better supporting medium.

When the load becomes very large, or the subsoil is incompetent, deep foundations are resorted to.

Piles and caissons are the two types of deep foundations.

Caissons are large diameter ($>$ 1m) concrete structures, circular or elliptical, sunk into the subsoil. They are also referred to as well foundations.

Piles are smaller diameter sections, either of wood, concrete or steel pipes. Steel H-section piles are also used often. They are either driven, jacked or pushed into the soil by means of vibrations. Piles are also cast-in-situ.

Normally the load transfer to the subsoil is achieved through friction between the pile wall and the soil. These are known as friction piles. When the load is transferred directly to the stratum on which the pile rests, it is referred to as an end bearing pile. Under normal circumstances part of the load is supported by the end point and most of it through side friction.

This work focusses attention on driven piles only.

Though piles are normally used in groups, the behaviour of the group can only be estimated from the knowledge of the single pile behaviour. Thus a thorough understanding of single pile behaviour is a must.

A lot of work has been carried out in the area of pile foundations to study pile behaviour, viz: estimation of bearing capacity, shaft resistance, ultimate load, buckling load, resistance as a function of L/d, resistance to lateral load, resistance to pull out, group behaviour etc.

Most of the work done is on the assumption that the as-driven pile is ideally straight.

There is enough evidence to show that piles do not always remain straight after being driven. The conditions

for an ideally straight driven pile can never be attained at least in the field. Either the pile to be driven is not "straight", or the driving mechanism, offset between hammer and pile, pile support, the variation of soil layers, presence of small boulders, the vibrations induced while driving, the splicing of pile segments and the directional in-stability caused by the flutter during driving- all lead to a bent pile.

Even extremely good driving conditions and a uniform soil stratum does not guarantee a "straight" driven pile.

As reported by Arumugam (1977), Glick (1948) derived an expression for buckling loads taking the case of an imperfect pile bent in n half sine waves. He assumed a differential equation for the elastic line of the pile.

Parsons and Wilson (1954) have presented solutions for safe loads on bent and dog legged piles. Marcus (as reported by Johnson 1965) showed that the residual stresses due to bending of piles were considerable. Madhav and Kurma Rao (1976) have shown the dependence of load carrying capacity on the shape of pile.

In the analysis of bent piles, various shapes of piles are assumed. For a better understanding it is essential that a proper shape be assumed.

This thesis aims to provide some experimental data on the shape of driven piles.

Not much work has been done in the area of bent piles. The same goes for field evidence. A review of available literature has been made in Chapter 2.

Very little field data is available on the shape of bent piles. None on model studies. The experimental set up and procedure for the model tests has been described in Chapter 3.

Chapter 4 presents the results and conclusions obtained from the model tests with a discussion on further work.

CHAPTER II

REVIEW OF LITERATURE

2.1 THEORETICAL WORK :

2.1.1 Work on Straight Piles :

Considerable amount of work has been done on pile foundations, assuming the piles to be ideally straight. The axial load capacity, lateral load capacity, behaviour under combined axial and lateral load, pull out resistance, buckling, group action, analysis of foundation of piles and pile groups have been studied.

2.1.2 Work on Bent Piles :

Not much work has been done on bent piles (as reported by Kurma Rao (1975)), Timeshenko (1936) first obtained solutions for the case of a uniform pin-ended imperfect pile in an elastic medium and gave an expression for buckling loads.

Glick (1948) assumed the pile shape to be n half sine waves and presented a solution.

Parsons and Wilson (1954) presented solutions for finding safe loads on dog legged piles.

Johnson (1962) has analysed bent piles based on Winklers hypothesis for estimating the capacity of cast-in-place pipe piles.

Broms (1963) has presented a method for calculating the maximum lateral deflection, maximum soil reaction and the maximum bending moment for an axially loaded initially bent pile.

Marcus (as reported by Johnson, 1968) presented a solution for pinned-pinned initially bent piles. He was the first to show that the residual stresses due to bending are considerable.

Francis et.al. (1965) have considered imperfections and loading eccentricities. They have shown that a pile with initial imperfectious has the same buckling load as a straight pile, but the lateral deflections before the critical load is reached, may be large.

Burgess (1975) has performed a dynamic analysis. He has shown that large out of swaying of piles is caused by, what is known in aerodynamics as 'flutter'. He predicts critical depths for H piles.

Kurma Rao (1975) has analysed bent piles using Winkler's hypothesis. He has determined the capacity of a bent pile as a function of the pile shape and offset. He observes that offsets of 1 to 2% reduce the pile capacity by about 25 and 50 % respectively for L/d ratio of 120 and 60. He also observes that the initial shape of the pile significantly affects the load carrying capacity and is more important than the boundary condition, as far as reduction in the load carrying capacity is concerned.

Arumugam (1977) has analysed the behaviour of bent piles based on the continuum model. He observes that the radius of curvature affects the load carrying capacity considerably and that piles with initial radius of curvature less than 475.0 times the diameter cannot carry any load. He has shown that the load carrying capacity of a bent pile is dependent on the actual pile shape, the L/d ratio and the offset.

2.2 FIELD MEASUREMENTS OF PILE SHAPE :

Parsons and Wilson (1954) have measured the shape of four piles. For the first one, 42.6 m in length (140 ft.), the maximum out of alignment measured at the bottom of the pile was 1.34 m (4.4 ft.). The bent pile was found to have a gentle sweep over the lower length. The second pile

had a dog legged shape with a maximum deflection of 3 ft. (1 m).

The first two piles were composite piles. The top section was corrugated pipe and the bottom section was ordinary pipe.

Two pipe piles were also found to have bent. One had a gentle sweep. The other pile had the shape of a sine wave.

Bjerrum (1957) reports the case of an H pile 30 ft. long. The maximum lateral deflection was observed to be 1.2 ft. Biaxial bending of piles was observed.

Johnson (1962) reports the shape of a composite pile with a maximum deflection of (8 ft.) 2.44 m , pile length was 27.44 m (90 ft.). The pile took a gentle sweep, with a sharp break at the joint.

Mohr (1963) reports the case of a pipe pile 25.9m (85 ft.) in length having a maximum deflection of 3.12m (10.25 ft.).

National Swedish Council (Hanna (1968)) reported a precast hexagonal hercules jointed pile 60 m long having a maximum deflection of 11.0 m. The pile took a gentle sweep.

Hanna (1968) reports of two steel H-piles 42.6 (140 ft.) and 39.55 m (130 ft.) long, the first one had a maximum out of alignment of 0.914 m (3 ft.) with triple curvature and relatively sharp direction changes, and the second had a maximum deflection of 1.83 m (6 ft.) with double curvature and relatively sharp directional changes.

Fellinius (1972) reports of a 40.71 m, 30 cm dia, concrete pile, having a maximum deflection of 2.65 m. Biaxial bending was observed.

Kim et.al. (1973) report the bending of steel H section piles 13.4 m in length (40 ft.), bending biaxially and with a maximum deflection of 10.4 ft.

TABLE 2.1

REPORTED PILE BENDING MEASUREMENTS

Reference	Pile Type	Pile Length (m)	Soil Type	Out of Alignment at tip(m)	Type of Bend
Parsons and Wilson(1954)	Composite Lower 26m, 27.4 cm dia pipe, top 16.8m corrugated pipe	42.8	6.1m fill, layers of organic silt, medium sand, fine sand, silt with clay layers gravel, bedrock	1.34	(1) dog legged with sharp change in curvature. (2) gentle sweep over lower length
Bjerrum (1957)	Steel H-section	9.14	Clay	0.366	Gentle sweep
Johnson (1962)	Composite Lower 12.2m, 27.4cm dia pipe top 15.24m corrugated taper pipe	27.46	6.1 silt overlying medium dense sand	2.44	Gentle sweep over lower length
Mohr (1963)	27.4 cm dia pipe	25.9	24.4m soft silt, stiffsandy clay medium dense sand	3.12	Gentle sweep
National Swedish Council(1964)	Precast hexagonal Hercules jointed	60.0	50m soft clay, 10m clay, sand rock at 70m	11.00	Gengle sweep

Reference	Pile Type	Pile Length (m)	Soil Type	Out of Alignment (m)	Type of bend
Hanna(1967)	Steel H-section 14BP73 and	42.6	10.4 stiff clay, 15.2m	0.914	Triple curvature relatively sharp direction change.
	14BP89	39.5	Soft clay, 19.5m stiff clay, shale	1.83	double curvature relatively sharp direction changes.
Fellenius (1972)	Precast concrete pile 30 cm dia	40.7	2.0m backfill of boulders 35 cm soft sensitive clays 3.0m sand and mud stone	0.19m in horizontal direction 2.65m in vertical direction	Gentle sweep double curvature
Jai B. Kim et.al.(1973)	Steel H-section 10BP42	13.4	8.0m clay 3.8m clay loam with limestone, gravel layers 1.6m limestone	Maximum 3.12m	Double curvature

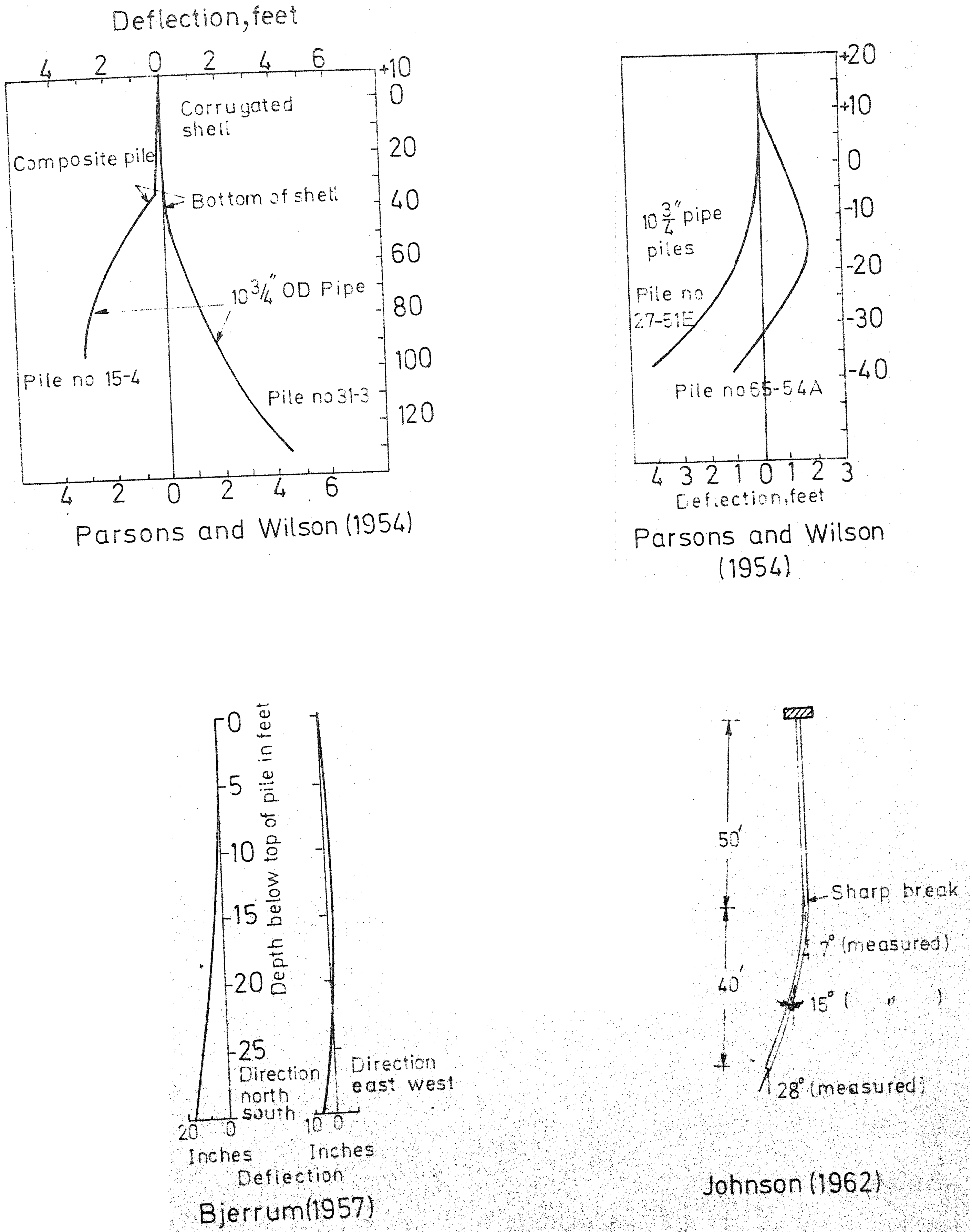
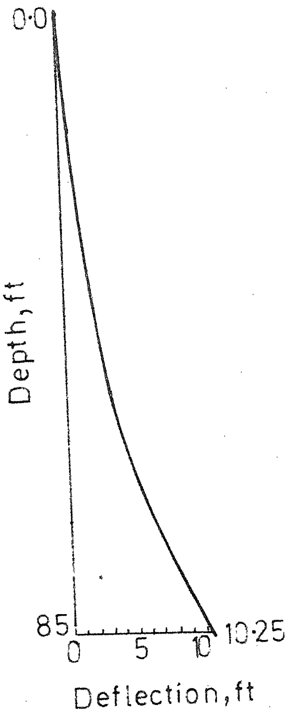
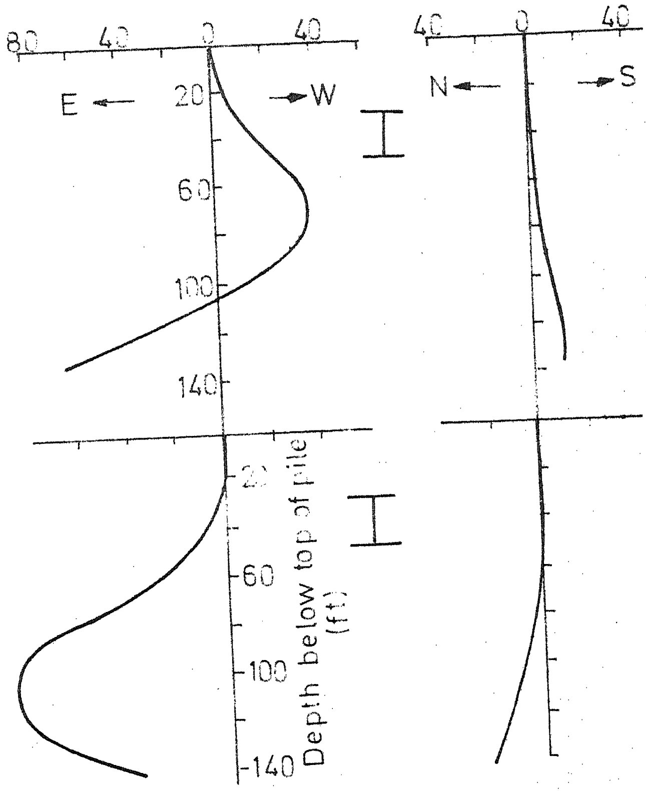


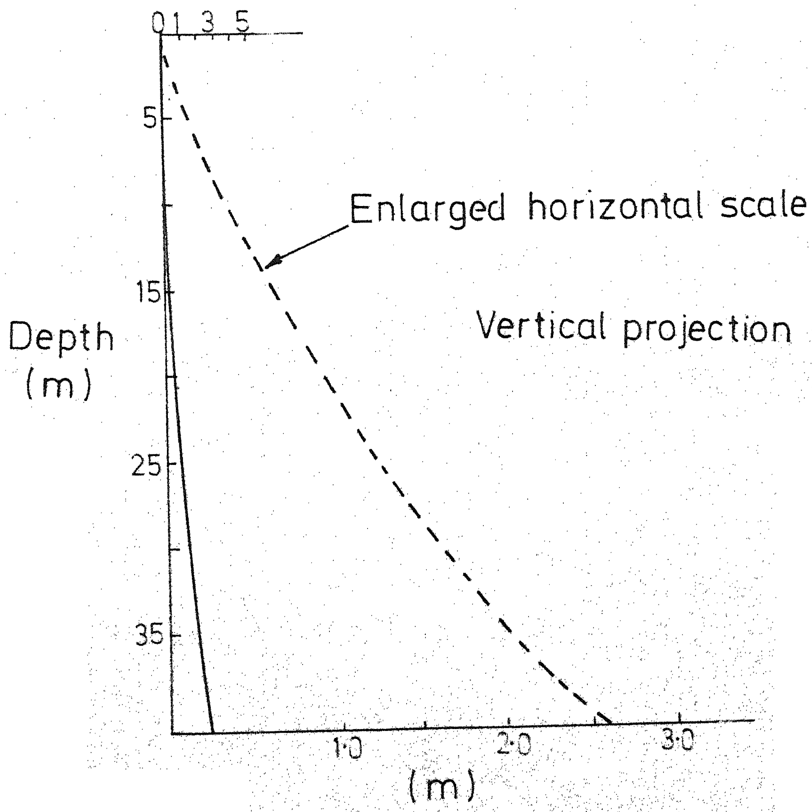
FIG. 2·1 FIELD MEASUREMENTS OF PILE SHAPE



Mohr (1963)

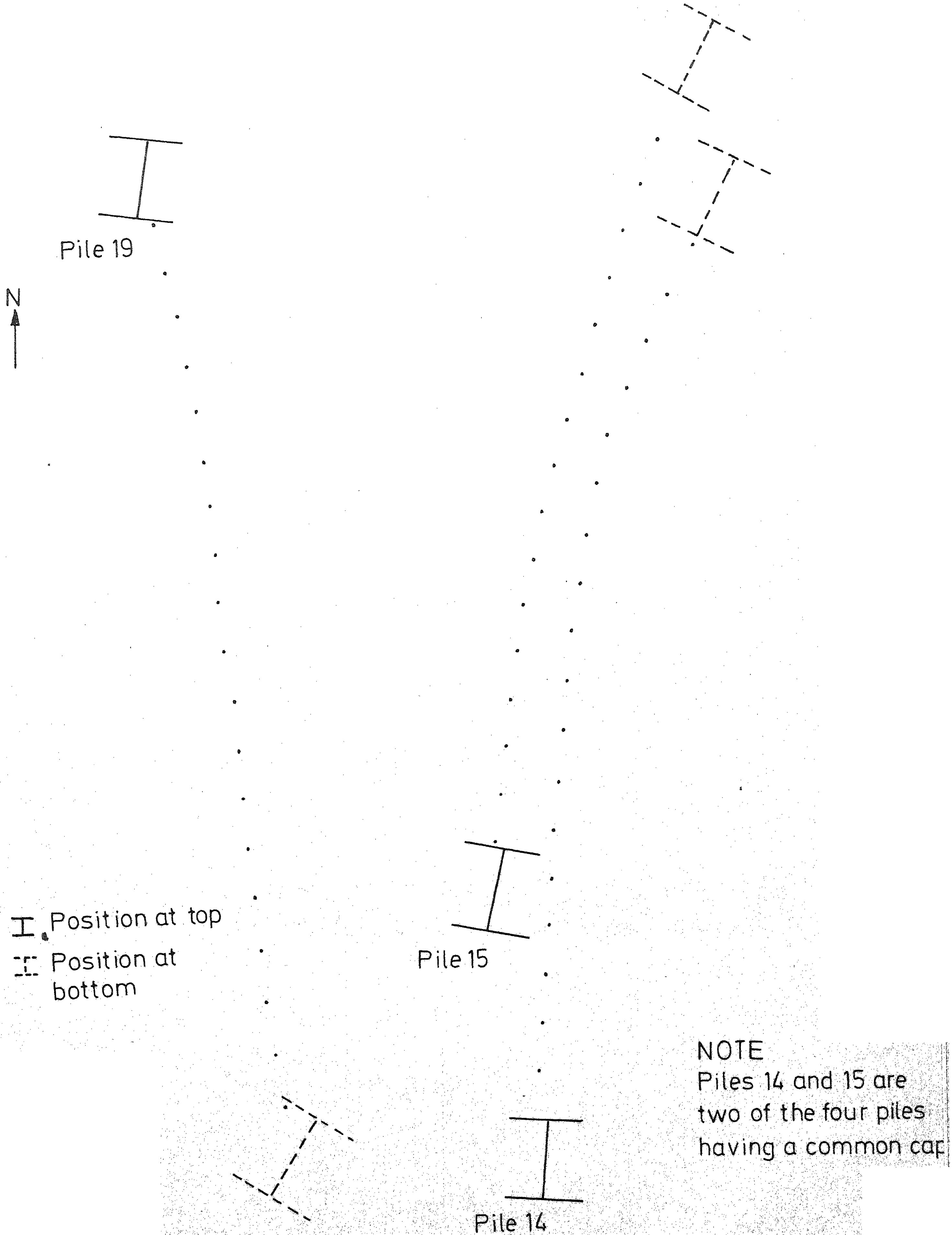


After Hanna 1968



After Fellenius (1972)

FIG.2·2



AFTER KIM et al (1973)

FIG.2.3 FIELD MEASUREMENTS OF PILE SHAPE

CHAPTER III

EXPERIMENTAL SETUP AND DETAILS

3.1 Very little information is available on the shape of bent piles. Data from few field tests only is available.

Conducting instrumented field tests is cumbersome and involves lot of time and money.

Model tests have an advantage over field tests in terms of the cost involved, the time saved, better instrumentation, variation of parameters and easier handling.

So far no model tests on the shape of piles have been reported in the literature.

3.2 The tests were performed in a rectangular steel tank 1.5 m x 0.75 m x 0.9 m. The tank had steel angles bolted on; to act as a track for the sand trolley. Dry Kalpi Sand was pourld through funnels on a wooden frame which had 1/4" size wire mesh. The maximum height of free fall for the sand was 15 cm. The frame was continuously adjusted so as to keep the height of free fall as constant as possible. The inplace bulk density of sand, measured

while pouring and after, was 1.7 gm/cc. One side of the tank was made of thick perspex sheet. It was observed that the sand was nearly uniform throughout its depth.

A slotted angle frame was designed so that it neatly fitted on the steel angles, over the tank. Once a test was performed it was moved easily to another position.

Wooden templates were used as guides for the piles. 1.5 cm. thick wooden plates with slots in the centre were used. 1 cm. diameter holes were drilled on the edges, so that the templates could be securely bolted to the slotted angle frame. Two templates, one at the top and one at the bottom were used as guides. The piles closely fitted the slots.

A 25.4 mm. dia drawn brass pipe, 30 cm. in length welded to a plate was used as a guide for the hammer. The guide was bolted to the frame, using a plumbline, to keep it vertical.

The hammer consisted of an aluminium rod, 25.3 mm. in diameter turned over a lathe, with markings every 2.54 cm. The hammer used to fall freely through the guide.

A wooden block was used as a cap, to prevent damage

to the pile. Holes were drilled so as that the lead wires from the strain gages could pass through.

The model piles were constructed of perspex sheets. The sheets were cut to the proper size over a milling machine so that smooth edges were obtained for better adhesion. Chloroform was used to join the strips together.

Type CT-10 strain gauges were used. These were fixed to the strips by pouring a few drops of chloroform over the marked point, After a few, seconds when the solution of chloroform and perspex thickened, the strain gauged was pressed into the proper position.

Hook up wires were then soldered to the leads of the gauges. The soldered joints were coated with dabs of Fevicol, an adhesive paste.

Once the strain gauges were fixed and the hook up wires soldered, the two halves of the section were joined together using chloroform. A compensating gage was fixed over a strip of perspex in the same way as all others.

Pile tips were machined from aluminium blocks. The angle of the pyramid was 60°. The pile tips were glued to the pile using chloroform.

The pile was then carefully held between the templates and using a plumbline, made vertical. Also the line of action of the hammer was made concentric to the pile, unless needed otherwise. The templates were then bolted firmly and the pile was held in place, vertical and concentric with the line of action of the hammer.

The strains were recorded using a Baldwin-Lima-Hamilton 120 strain indicator, Two BLH switching units 10 channels each were used along with the strain indicator.

Before the driving operation began, strain were recorded.

The fall of hammer was carefully controlled manually and the hammer was dropped manually too. The penetration after each fall was recorded.

After driving the pile, the strains were again recorded. The difference between the two gave the strain induced due to driving.

The hammer itself was used as a loading mechanism for load test. Threads were provided at the top and bottom so that a loading plate could be bolted on the top. At the bottom of the hammer an aluminium pipe with threads was

screwed on to the hammer. The aluminium pipe had a small aluminium rectangular section fixed to it. This acted as a point of reference for the dial gauge. The aluminium pipe had a hole drilled on its side so that the lead wires from the strain gauges could pass through it to the strain indicator.

For performing lateral load tests a hoop was made out of wires which could be inserted over the pile. This hoop was attached firmly to double stranded wire. A pulley was attached to the frame and a loading pan was then tied firmly to the wire coming over the pulley. Weights were added to the loading pan. The pulley and the hoop were on a horizontal plane. A dial gauge was fixed to the frame to measure the lateral deflections of the pile.

For the pull-out test a strong wire was inserted into a small hole drilled into the perspex plate. This plate was fixed to the top of the pile using chloroform. The wire then passed over a pulley attached to the frame, and a loading pan was tied at the other end. The dial gauge point rested on the perspex plate.

3.3 EXPERIMENTAL PROCEDURE :

3.3.1 Pile Driving :

The pile was adjusted concentrically with the hammer, except where an offset was provided, and kept vertical with the aid of templates. A plumbline was used to keep the pile vertical.

Strains were recorded after the piles were installed, with the help of BLH model 120 strain indicator.

The drop of the hammer was kept constant using a small scale. In all the cases the drop was 3 in. except in the case of pile # 1.

The hammer was lifted manually and dropped on the wooden cushion over the pile.

Pile penetration was recorded after each blow.

Once the pile was driven, strains were recorded. The difference between the two recordings gave the strains due to driving.

3.3.2 Axial Load Test :

After the pile was driven the hammer was used to

transfer the axial load. An aluminium pipe fitted with a rectangular piece of aluminium was screwed on to the hammer. The dial gauge fitted to a magnetic holder was attached and the initial reading taken.

The loading plate was then screwed on to the top of the loading mechanism. The change in the dial gauge was recorded. Weights were then placed in steps on the loading gauge. The displacement readings under each load were taken upto 20 minutes approx. or till the dial gauge needle reached a constant value.

Loading was continued till failure, or to a settlement b/2, b equals the larger dimension of the pile cross section.

3.3.3 Lateral Load Test :

During pile installation, a wire hoop was inserted over the pile. This was attached to a double stranded wire. A loading mechanism was attached to the steel frame. Care was taken to make the wire horizontal, so that a purely horizontal load was applied.

A dial gauge attached to the magnetic holder was fixed to the loading frame and its end rested on the pile.

The initial reading of the dial gauge was recorded.

Weights were placed in a pan which was attached to the double stranded wire passing over a pulley.

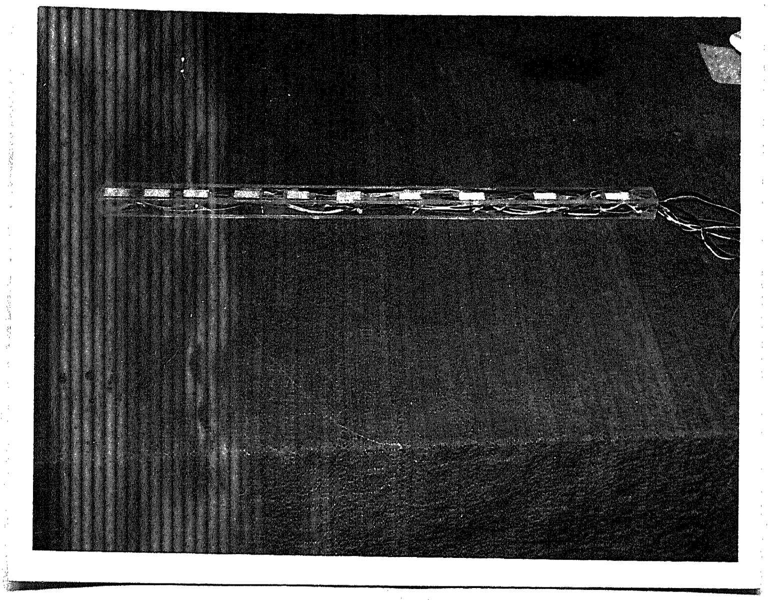
After each load increment sufficient time (approx. 20 min.) was allowed before the deflection was recorded.

3.3.4 Pull Out Test :

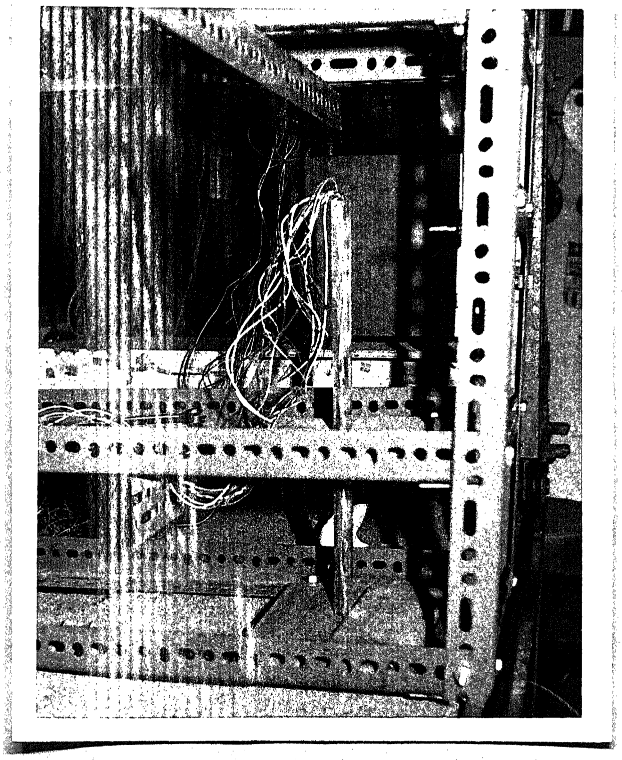
A perspex plate with a wire attached to it through a small hole was joined to the pile top using chloroform. The wire passed over a pulley and a pan was attached to it.

The dial gauge rested on the perspex plate.

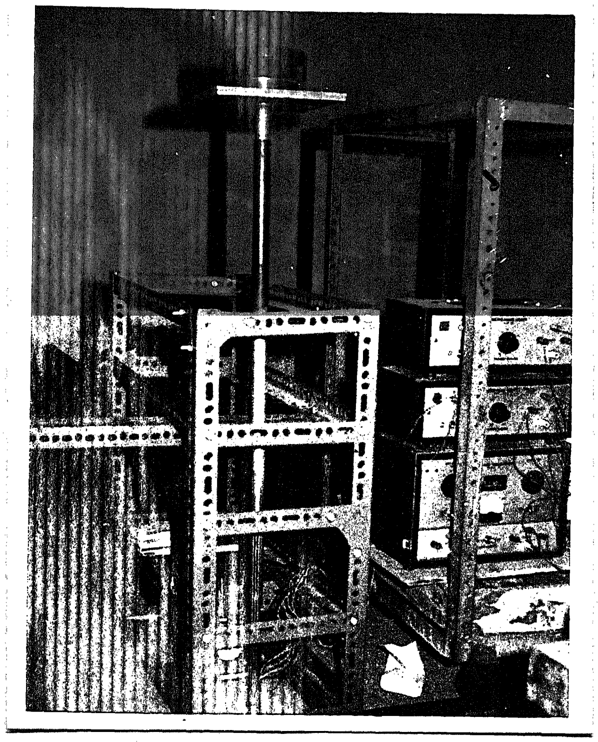
Weights were placed on the pan and the deflections recorded upto a sufficient amount of time usually 20-30 minutes.



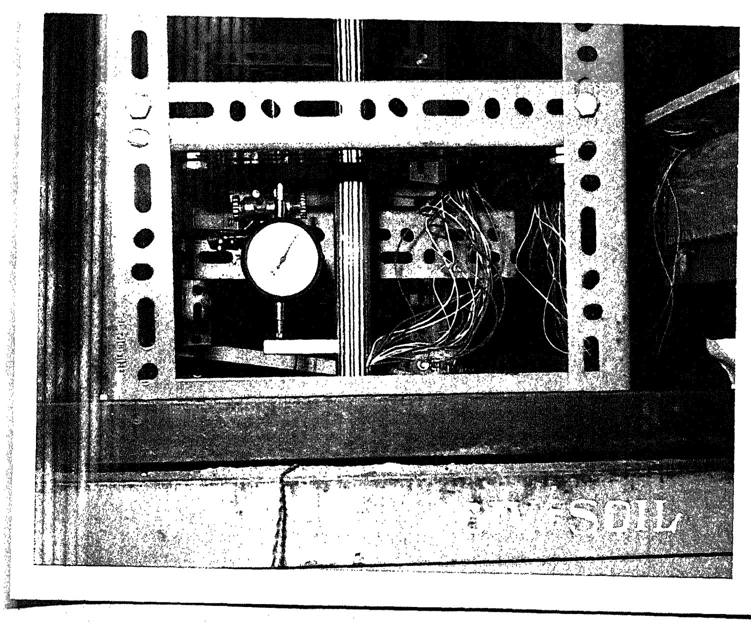
MODEL PILE



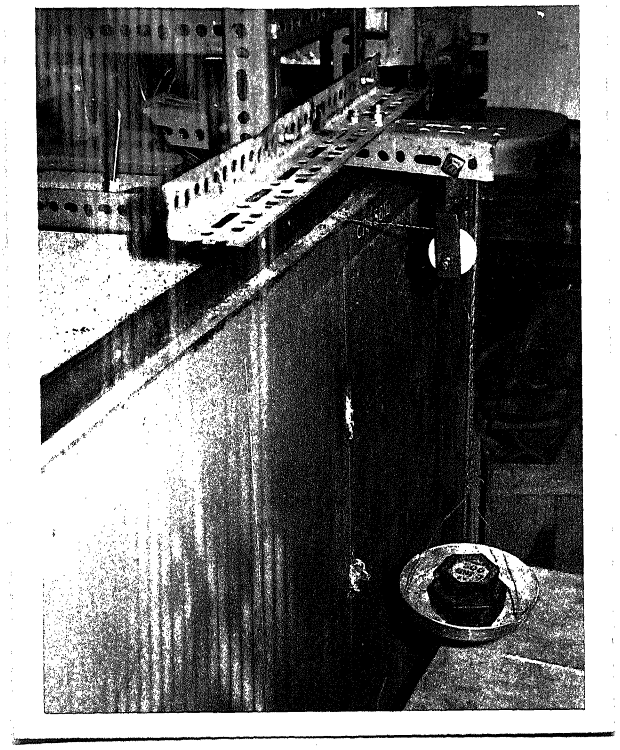
BEFORE DRIVING



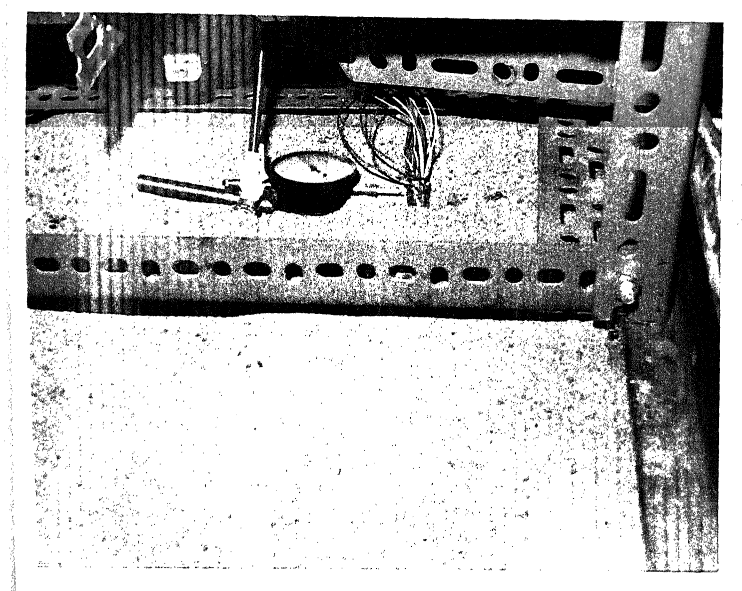
AXIAL LOAD TEST



AXIAL LOAD TEST



LATERAL LOAD TEST



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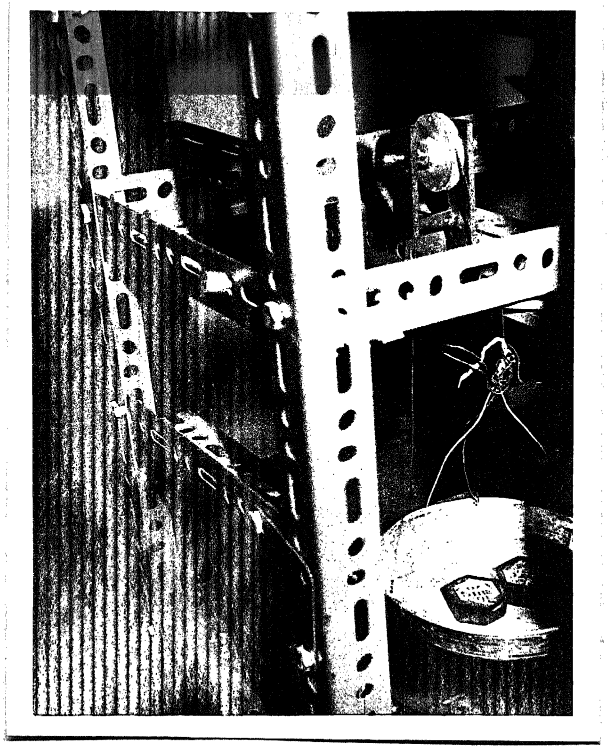
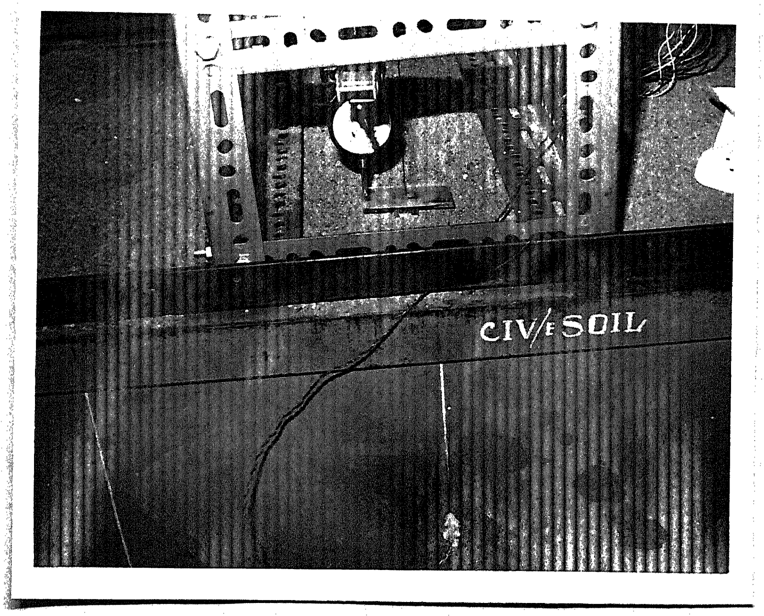


PULL OUT TEST



PULL OUT TEST

CHAPTER IV

RESULTS AND DISCUSSION

Pile foundations form a subdivision of deep foundations.

In practice piles seldom remain "straight" after being driven. A number of effects come into play and the ultimate result is a bent pile.

The relatively small amount of work done on bent piles clearly demonstrates the behaviour of a bent pile is quite different from the behaviour of a "straight" pile. The initial shape and the maximum offset are the two most important considerations in the design of bent piles.

So far only a small number of field measurements have been made to get the actual pile shape. No model studies have been carried out to get the actual pile shape.

Twelve model piles were driven in a uniform sand bed. The strains were then recorded using a BLH model 120 strain indicator.

From bending theory,

$$\sigma_x = \frac{M\,y}{I} \tag{4.1}$$

$$\sigma_x = E\,e_x \tag{4.2}$$

and

$$\frac{d^2 v}{d\,x^2} = -\frac{M}{EI} \tag{4.3}$$

Substituting. For σ_x in equation 4.1 one gets

$$E\,e_x = \frac{M\,y}{I}$$

or

$$M = \frac{E\,e_x\,I}{y} \tag{4.4}$$

Substituting for M in equation 4.3 ,we have

$$\frac{d^2 v}{d\,x^2} = -\frac{E\,e_x\,I}{y\,E\,I} = -\frac{e_x}{y} \tag{4.5}$$

This gives the equation for the elastic line of the pile.

Integrating equation 4.5 twice with the boundary conditions

$$v = 0 \quad \text{at} \quad x = 0$$

$$\frac{d\,v}{d\,x} = 0 \quad \text{at} \quad x = 0$$

One gets,

$$v = \left[- \int_0^L \int_0^L \varepsilon \; dx dx \right] / y \qquad (4.6)$$

Equation 4.6 gives the shape of the pile.

A curve expressed as a polynomial was fitted to the observed strain data.

A set of simultaneous equations were then solved using IBM 7044/1401 to get the coefficients for the polynomial.

The polynomial was then integrated twice and the equation for the shape of the pile was obtained. The shape of the pile was plotted with the aid of x-y plotter. The shapes obtained are shown at the end of this chapter (Figs. 4.4 to 4.18).

Due to the unavailibility of a larger tank, piles with larger L/d ratios could not be tested.

Interesting shapes have been obtained. They can form a basis for future analyses and design.

Pile sections properties, the relative stiffness factor K_R, L/d, cross sectional area, moment of inertia about the weak axis have been tabulated in Table 4.1.

Pile shapes have been plotted for compressive load effects (Figs. 4.19 onwards). The shape at ultimate load has been plotted. There is a marked change from the original pile shape in most of the cases.

Axial load test results have been plotted in Figs. 4.1 and 4.2 . The pile length could not be varied much but the cross-sectional area was varied. As the cross-sectional area decreases the ultimate load capacity of the pile too decreases.

Lateral load test results have been plotted in Fig. 4.3.

As the moment of inertia about the weak axis decreases, larger deflection for the same load is obtained.

Ultimate pull-out resistance has been tabulated in Table 4.1. Since the pile was virtually smooth(as the pile material was perspex) the ultimate pull-out resistance is very small. The average value of shaft resistance is only 5.45 g/cm^2.

Assuming a similar value for shaft resistance under compressive load, the shaft load turns out to be a small fraction of the ultimate load capacity of the pile. The load is transmitted through point or tip resistance only.

4.1 Concluding Remarks :

It is practically impossible to drive "straight" piles. There is enough evidence to prove that.

The analysis of bent piles shows the dependence of pile behaviour on the shape and the maximum off-set.

As driven pile shapes have been obtained (Figs. 4.4 to 4.18) and also the shapes at the ultimate load (Figs. 4.19 to 4.30). Considerable change in shape is observed.

Axial load tests, lateral load tests and pull-out tests have been carried out and the results plotted.

4.2 Suggestions for Further Work :

1. Deeper tank should be fabricated so that larger L/d ratios upto 200 can be tested.
2. Effect of layered media should be investigated.
3. Theoretical analysis of pile-driving . Mechanism taking into account the soil variability and variable pile section.

TABLE 4.1

S. No.	Pile No.	Length (cm)	Cross section cm x cm	Surface Area cm^2	Cross-sectional Area cm^2	P_{ult} (Pull-out) (g)	P_{ult} (compr.) kg.	L/d	P_b	*	**	K_R
1	1	35	2.54 x 2.54	355.6	6.45	1500	20.1	13.77	18.6	8.06	4.2	10^{-2}
2	2	35	2.54 x 2.54	355.6	6.45	1800	21.5	13.77	19.7	9.10	5.06	10^{-2}
3	3	45	2.54 x 2.54	457.2	6.45	3600	26.5	17.72	22.9	15.70	7.80	10^{-2}
4	4	35	2.54 x 2.54	355.6	6.45	2700	-	13.77	-	-	7.60	10^{-2}
5	5	35	1.9 x 1.9	266.0	3.61	1800	24.47	18.42	22.6	7.90	6.70	10^{-3}
6	6	35	2.54 x 1.27	266.7	3.22	1650	14.2	27.55	12.5	12.80	6.18	10^{-3}
7	7	35	d = 1.0	259.0	3.10	1300	11.1	35.00	9.8	13.2	5.00	10^{-3}
8	8	45	2.54 x 1.27	342.9	3.22	1470	11.09	35.40	9.62	14.5	4.30	10^{-4}
9	9	45	2.5 x 0.9	306.0	2.25	1015	7 .01	50.00	6.0	16.9	3.30	10^{-3}
10	10	35	1.95 x 1.2	220.5	2.34	1200	12.90	29.20	11.7	10.2	5.50	10^{-3}
11	11	45	2.9 x 1.6	405.0	4.64	1900	21.98	28.12	20.1	9.13	4.70	10^{-4}
12	12	44.5	2.8 x 1.65	396.05	4.62	2040	23.8	26.96	21.8	9.3	5.15	10^{-4}

* $\dfrac{\text{Pullout Resistance}}{P_{ult}(\text{Compr.})} \times 100$

** Pullout Resistance/Unit Area

TABLE 4. 2

Pile No.	Length cm	I_{yy} (cm^4)	K_R
1	35	2.28	10^{-2}
2	35	2.28	10^{-2}
3	45	2.28	10^{-2}
4	35	2.28	10^{-2}
5	35	0.85	10^{-3}
6	35	0.385	10^{-3}
7	35	0.39	10^{-3}
8	45	0.385	10^{-4}
9	45	0.147	10^{-3}
10	35	0.256	10^{-3}
11	45	0.811	10^{-4}
12	44.5	0.835	10^{-4}

TABLE 4.3

PILE DEFLECTION AFTER DRIVING

PILE	LENGTH (cm)	c_x (cm)	c_y (cm)	c_x/L %	c_y/L	
1	35	-	-	-	-	
2	35	0.017	0.14	0.048	0.4	
3	45	0.17	0.79	0.37	1.75	
4	35	0.019	0.5	0.05	1.4	Hammer (offset 2.4 cm)
5	35	0.023	0.02	0.065	0.06	
6	35	0.015	-	0.044	-	
7	45	0.36	-	0.8	-	
8	45	0.2	-	0.44	-	
9	45	0.28	-	0.62	-	
10	35	0.15	-	0.43	-	
11	45	0.5	-	1.1	-	
12	45	0.85	-	1.8	-	Hammer (offset 1.7 cm)

TABLE 4.4

PILE DEFLECTION DURING AXIAL LOAD TEST

PILE	LENGTH (cm)	c_x (cm)	c_y (cm)	c_x/L (%)	c_y/L (%)
1	35	-	-	-	-
2	35	-	-	-	-
3	45	0.4	0.7	0.8	1.5
4	35	-	-	-	-
5	35	0.02	0.06	0.06	0.16
6	35	0.7	-	2.0	-
7	45	1.2	-	2.6	-
8	45	0.5	-	1.1	-
9	45	0.4	-	0.8	-
10	35	0.48	-	1.3	-
11	45	0.81	-	1.8	-
12	45	0.35	-	0.76	-

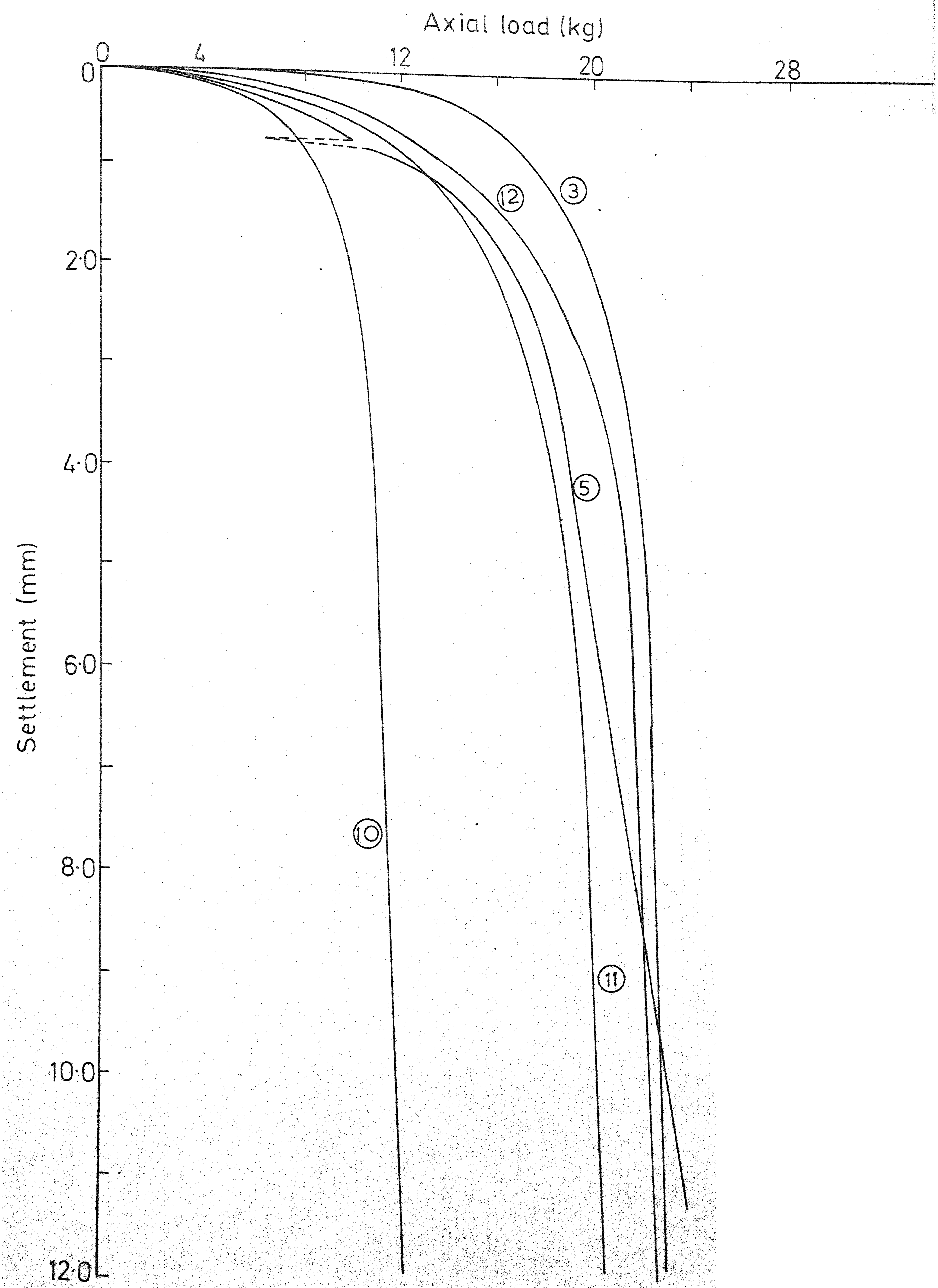

Axial load (kg)
0
4
12
20
28
0
2.0
4.0
6.0
8.0
10.0
12.0
Settlement (mm)
3
12
5
10
11

FIG. 4.1

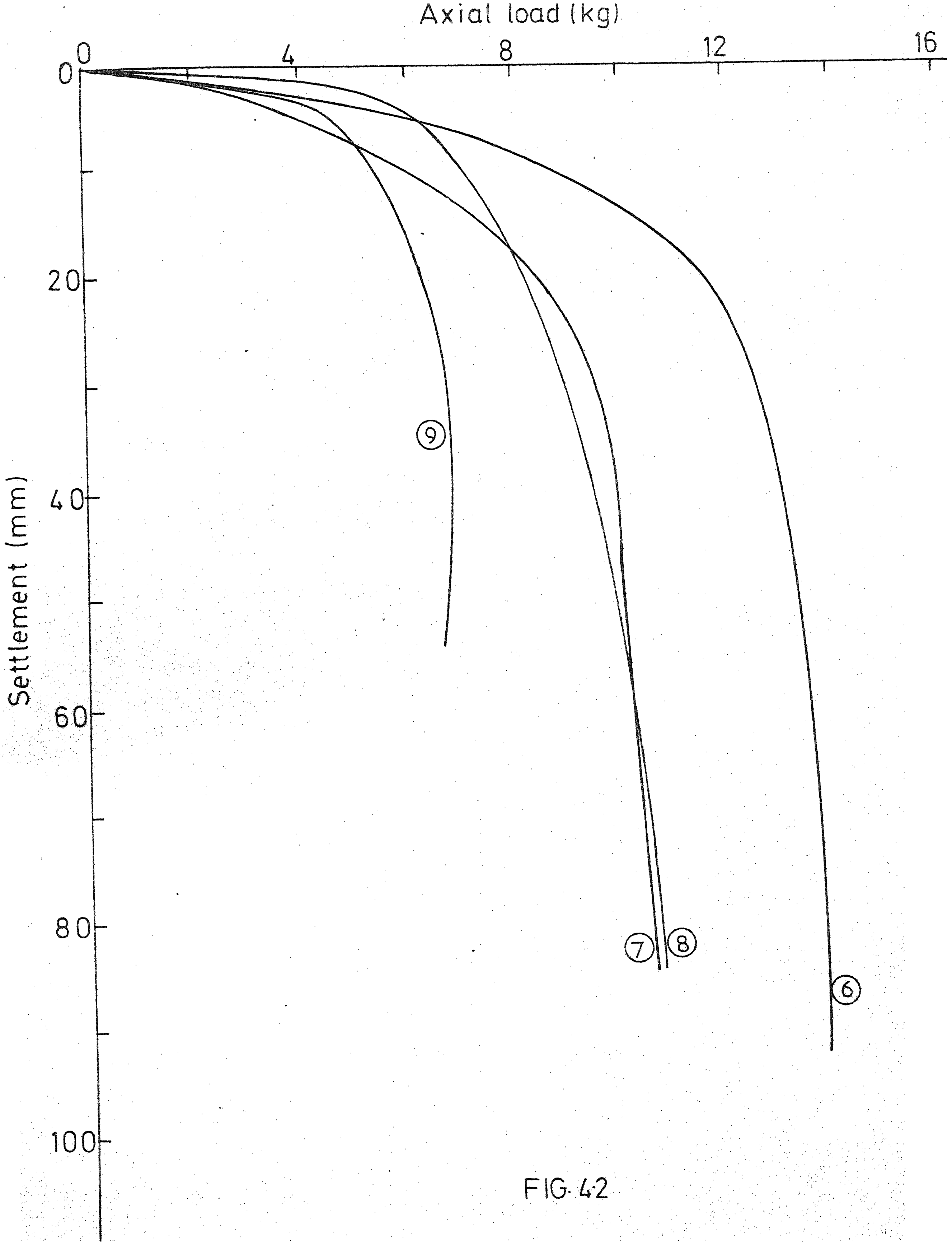
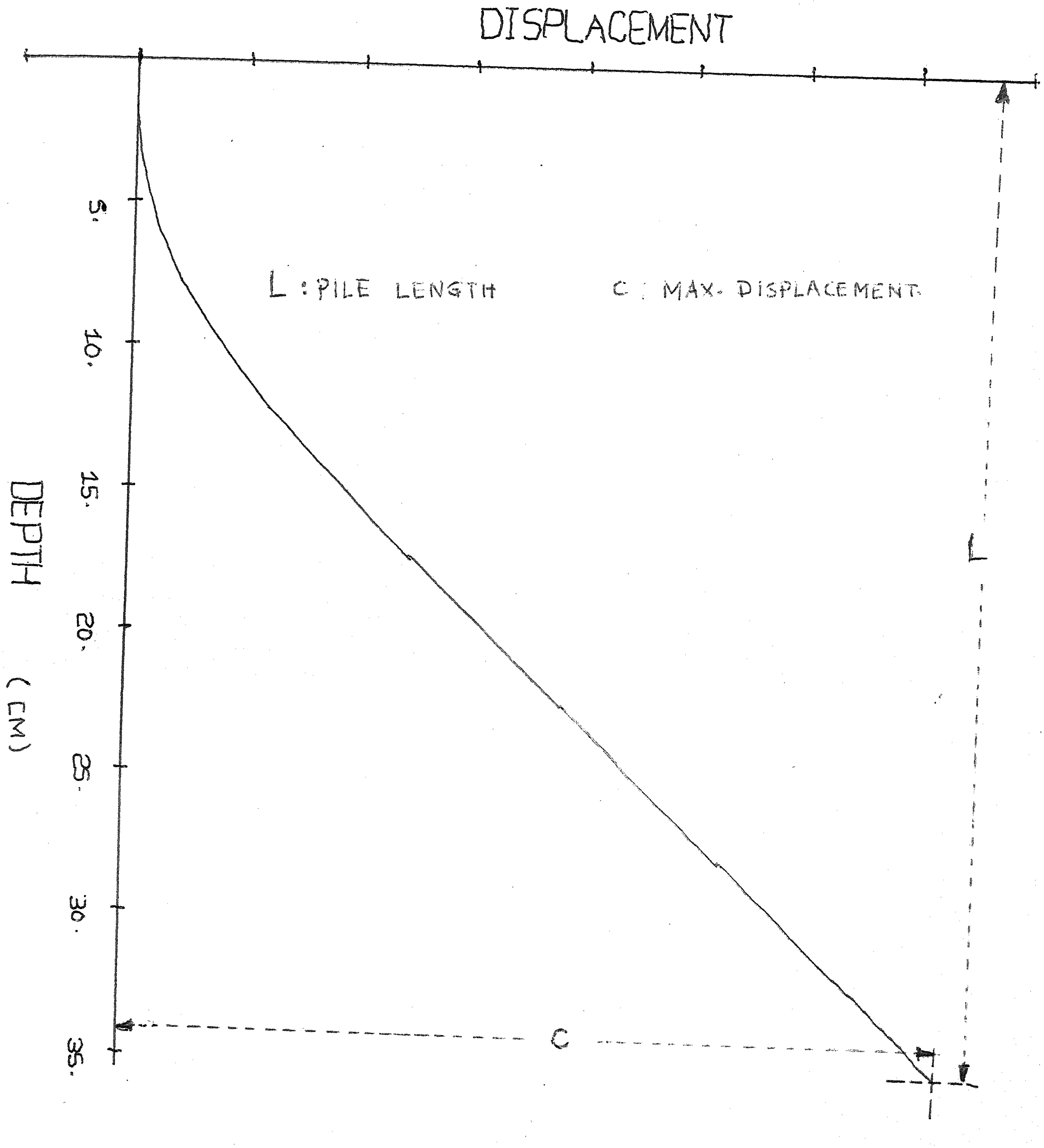
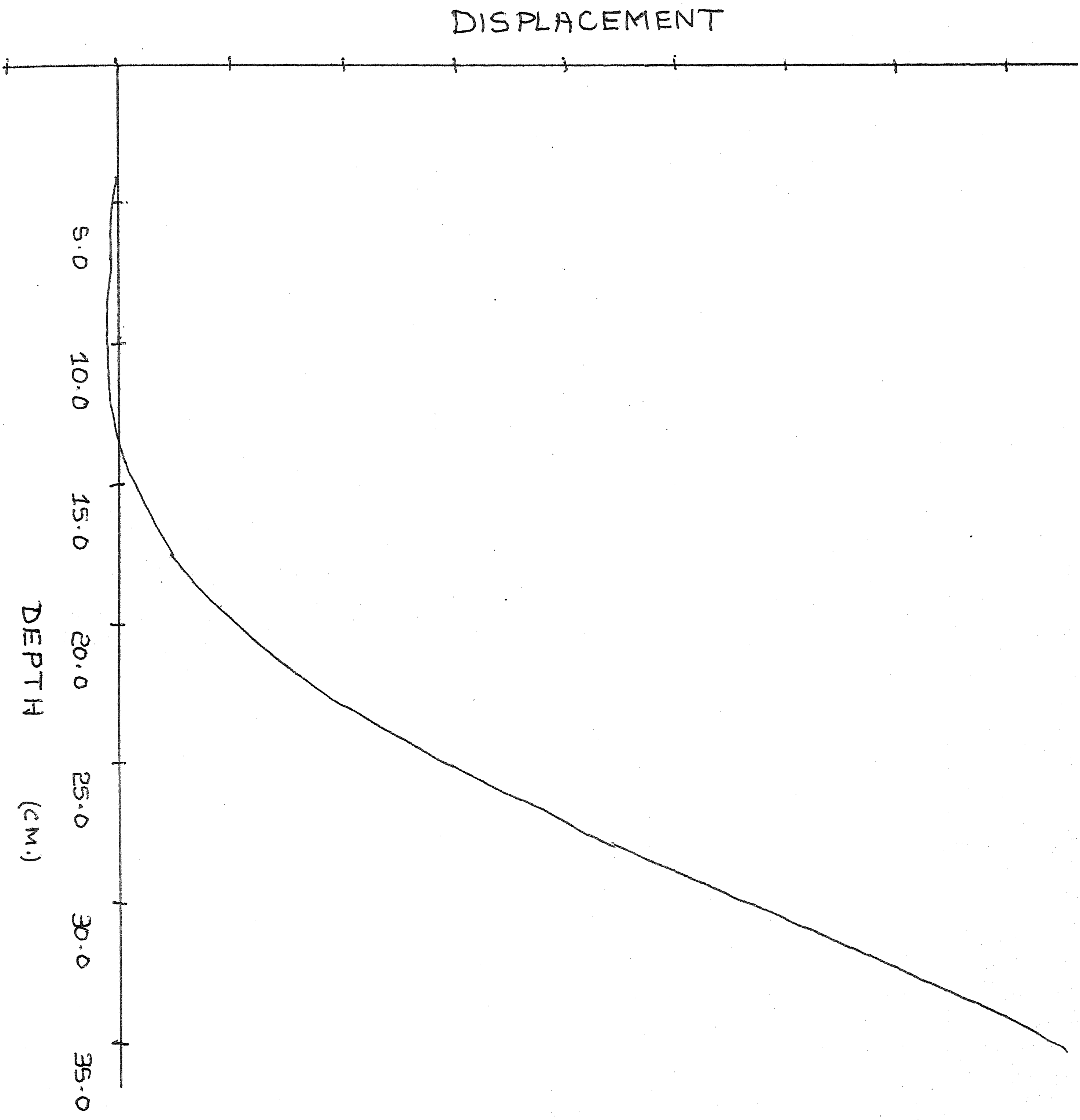


FIG. 4.2

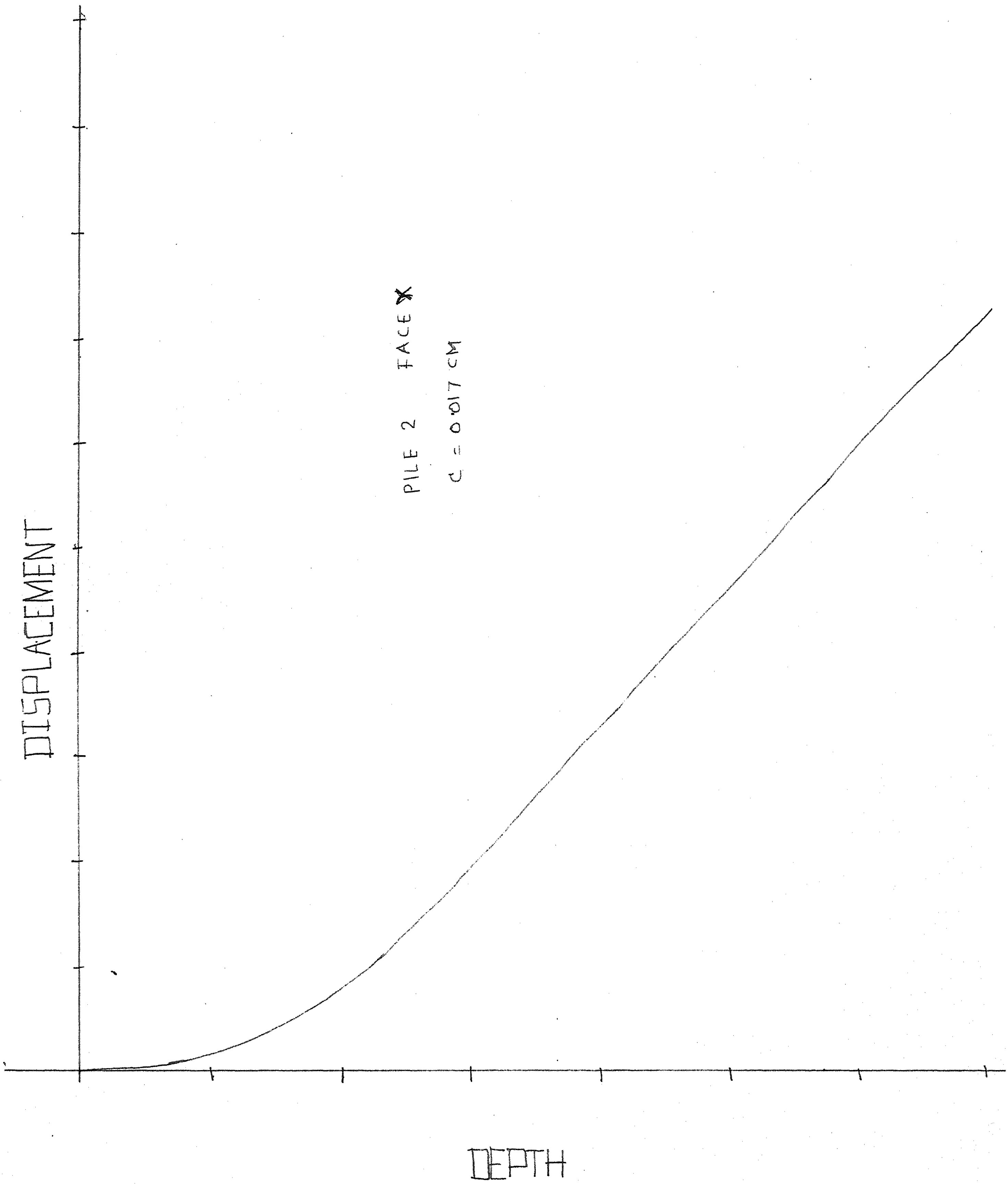


DEFN. OF TERMS

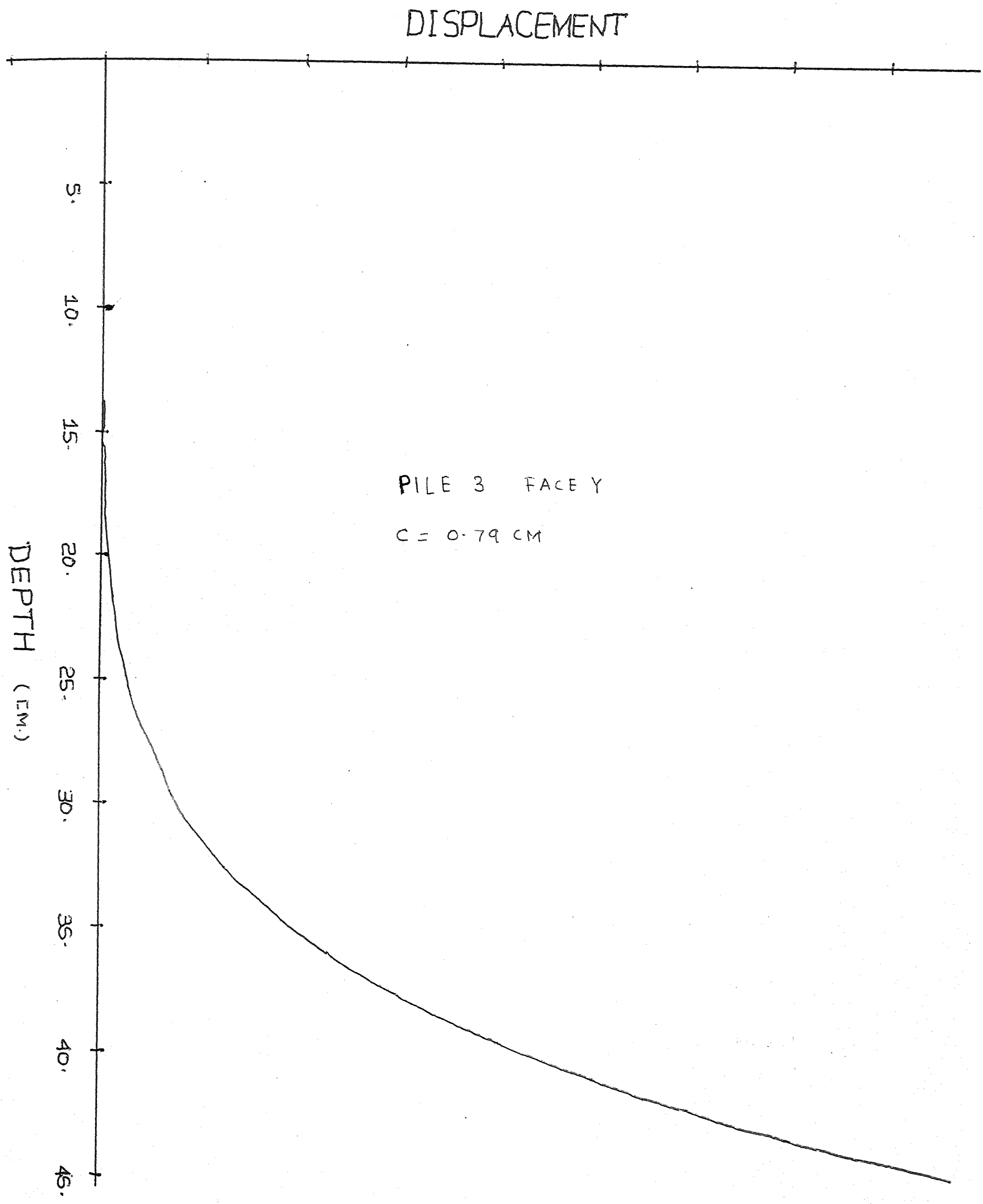


PILE 2 FACE Y

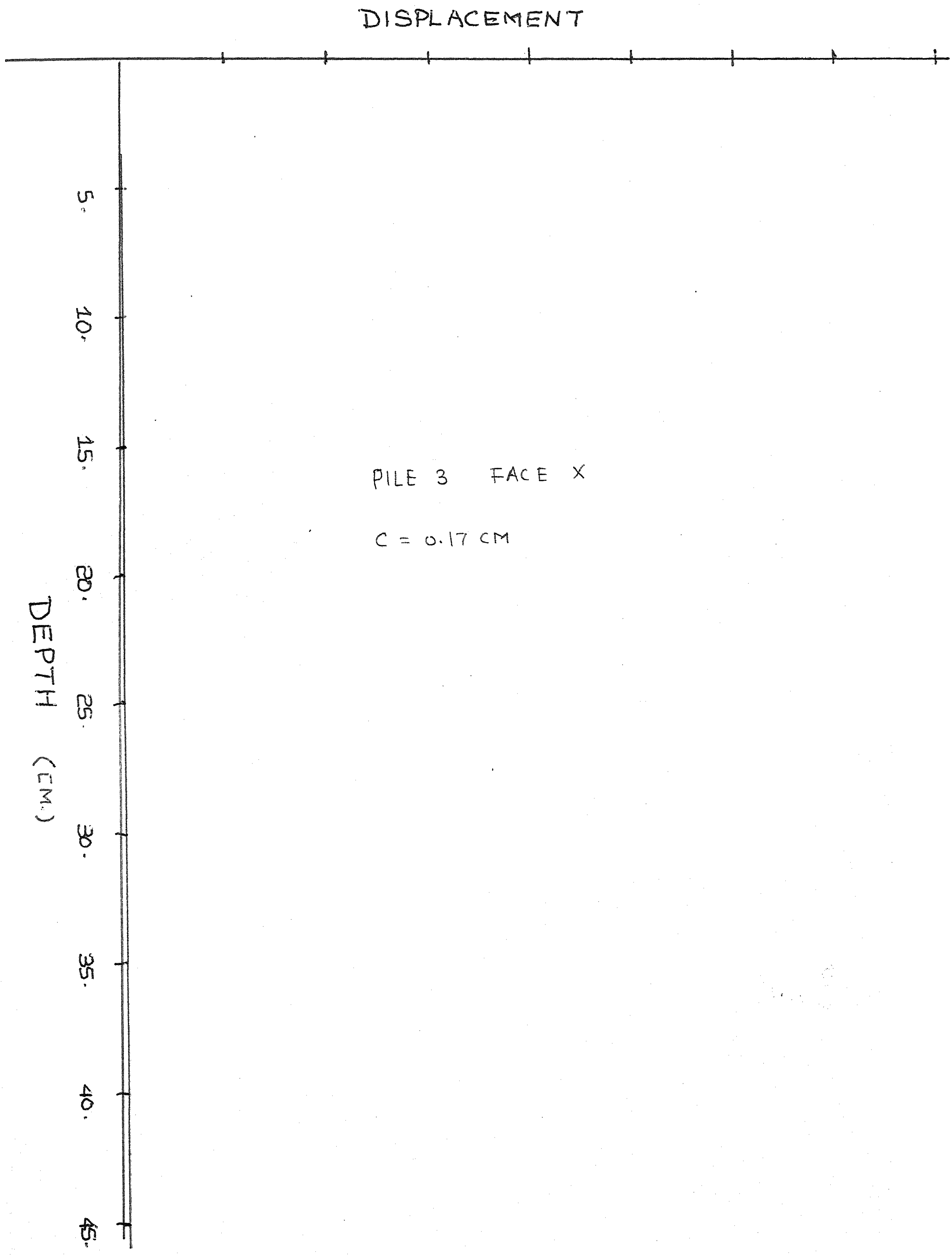
C = 0.14 CM



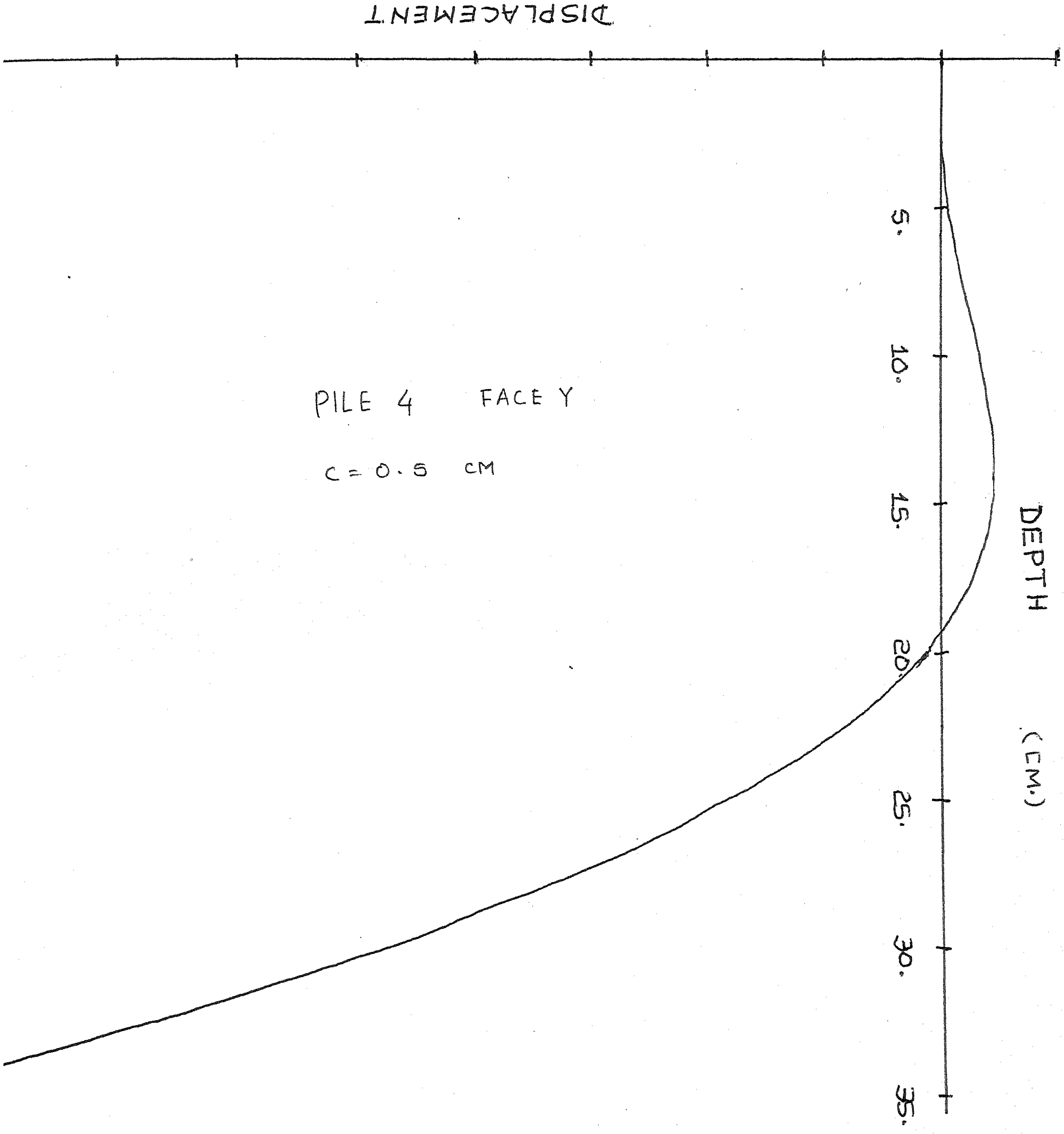
DISPLACEMENT
DEPTH
PILE 2 FACE X
C = 0·017 CM

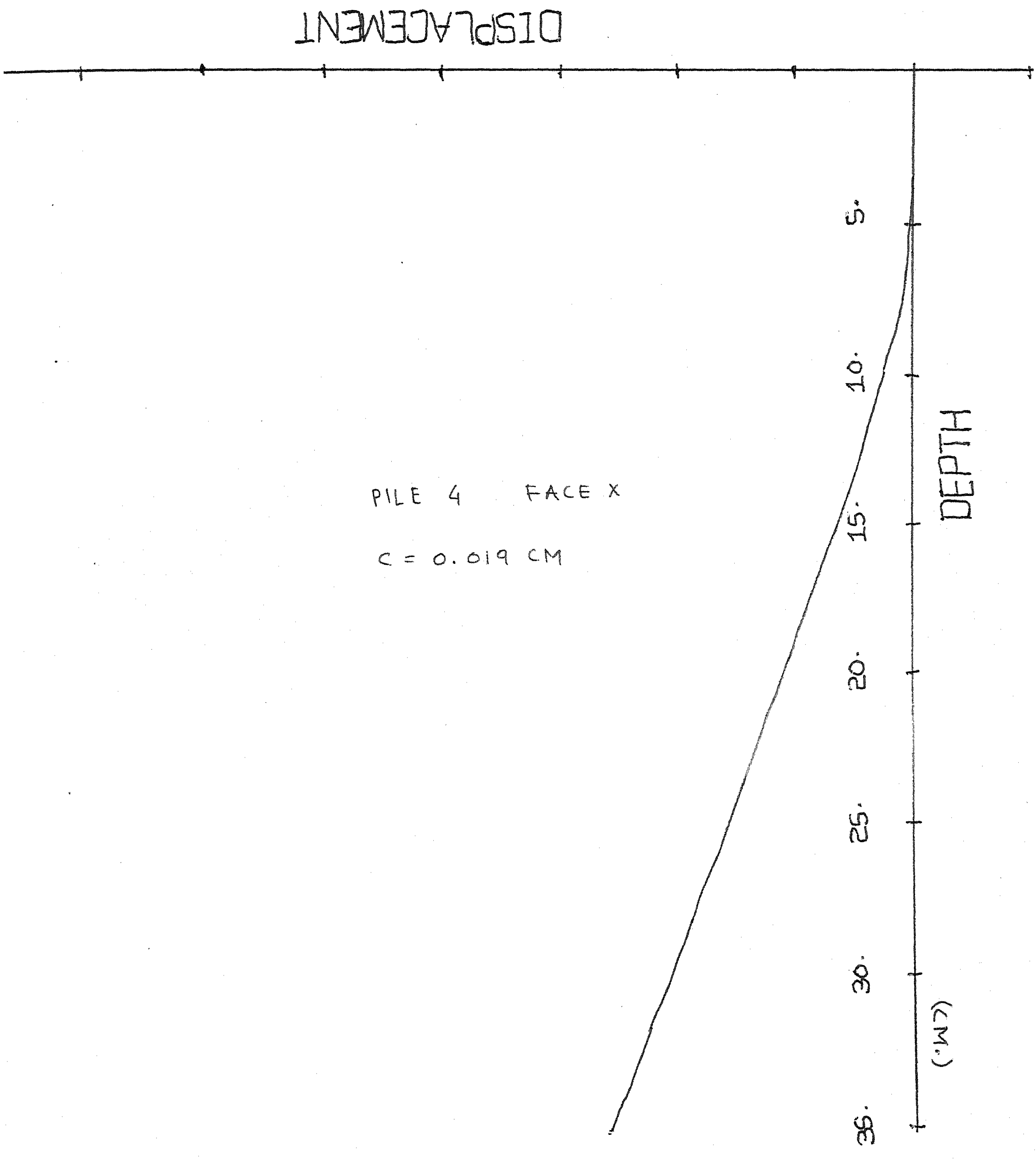


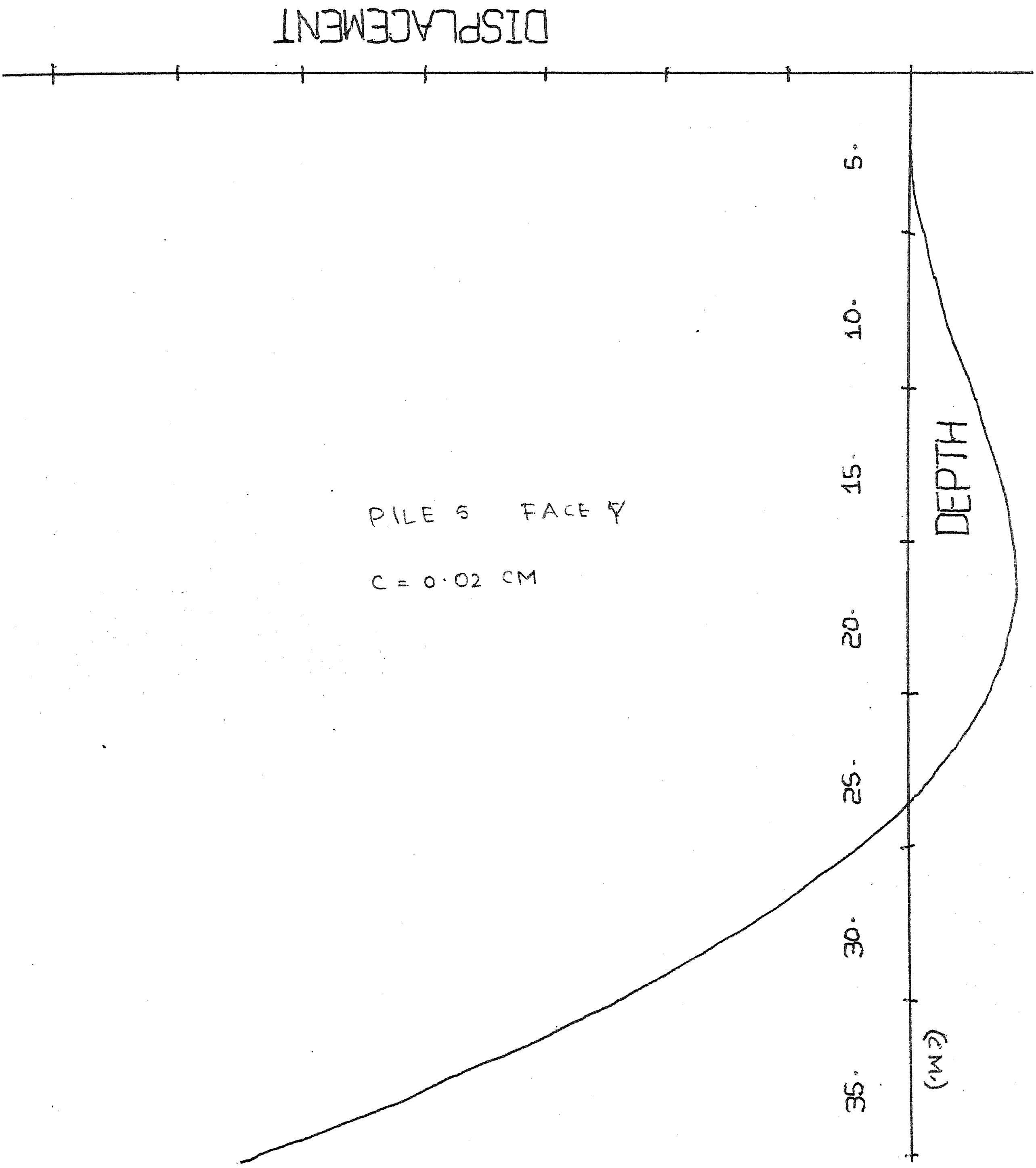
DISPLACEMENT
DEPTH (CM.)
5.
10.
15.
20.
25.
30.
35.
40.
45.
PILE 3 FACE Y
C = 0·79 CM

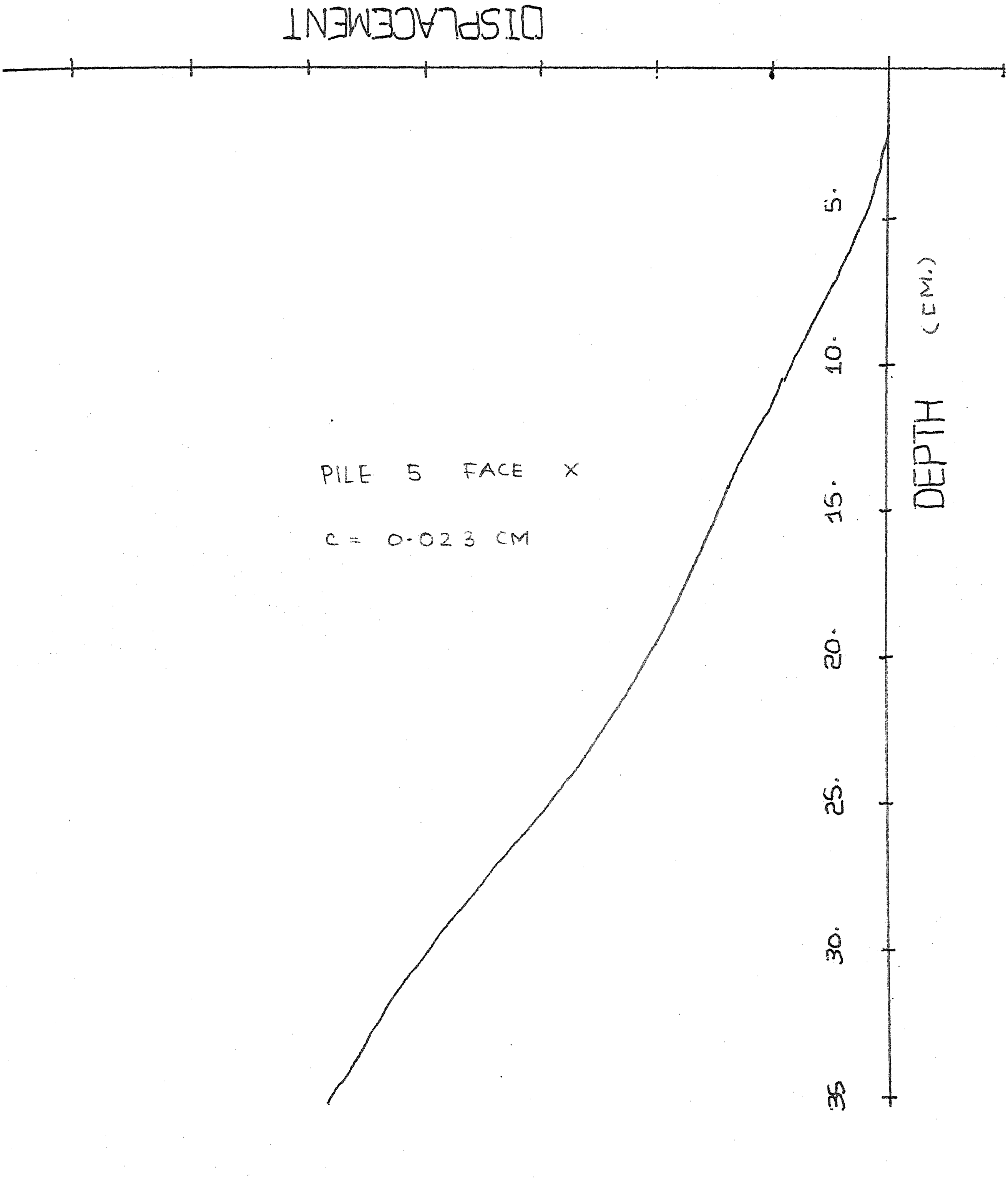


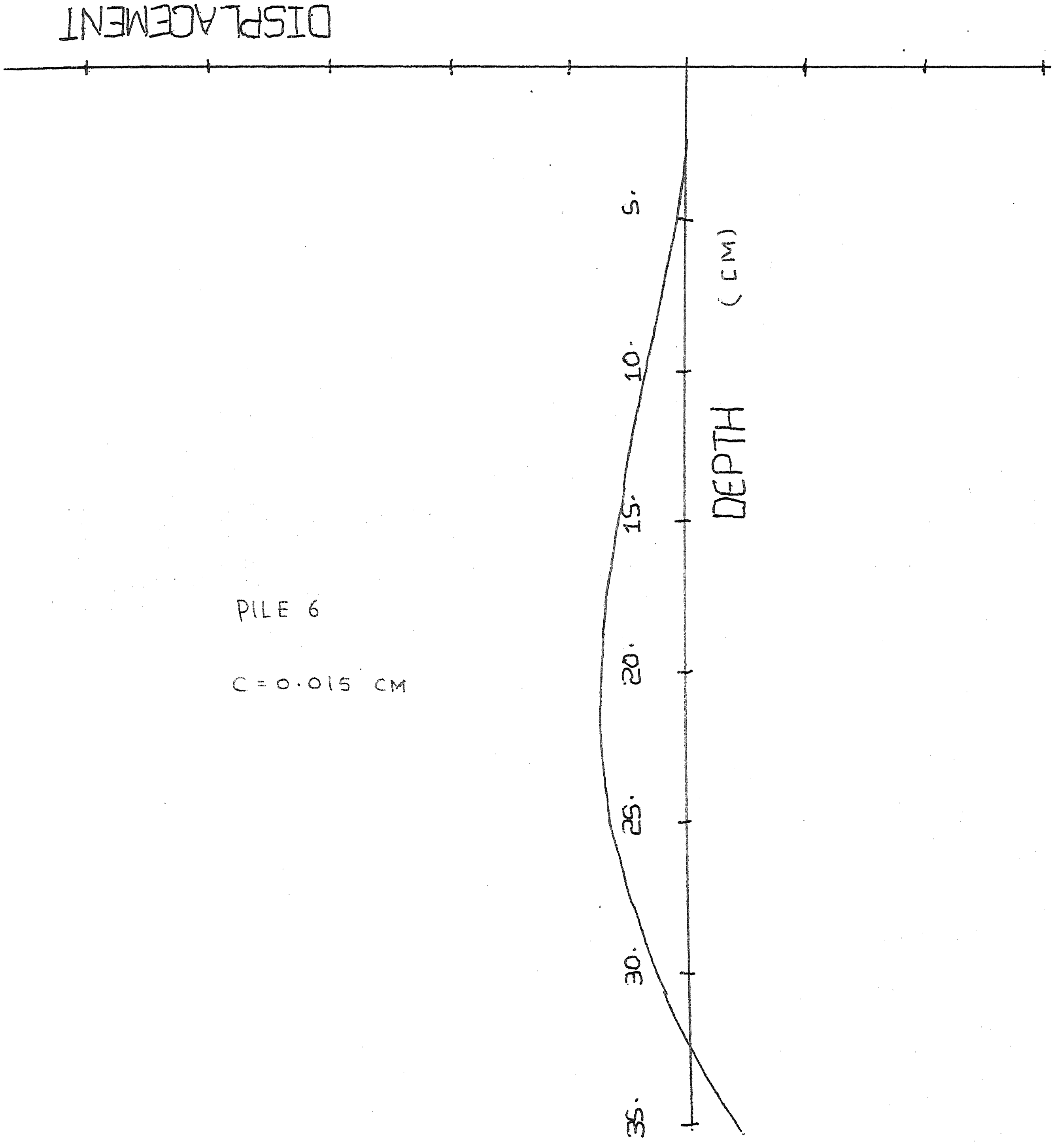
DISPLACEMENT
DEPTH (CM.)
5.
10.
15.
20.
25.
30.
35.
40.
45.
PILE 3 FACE X
C = 0.17 CM

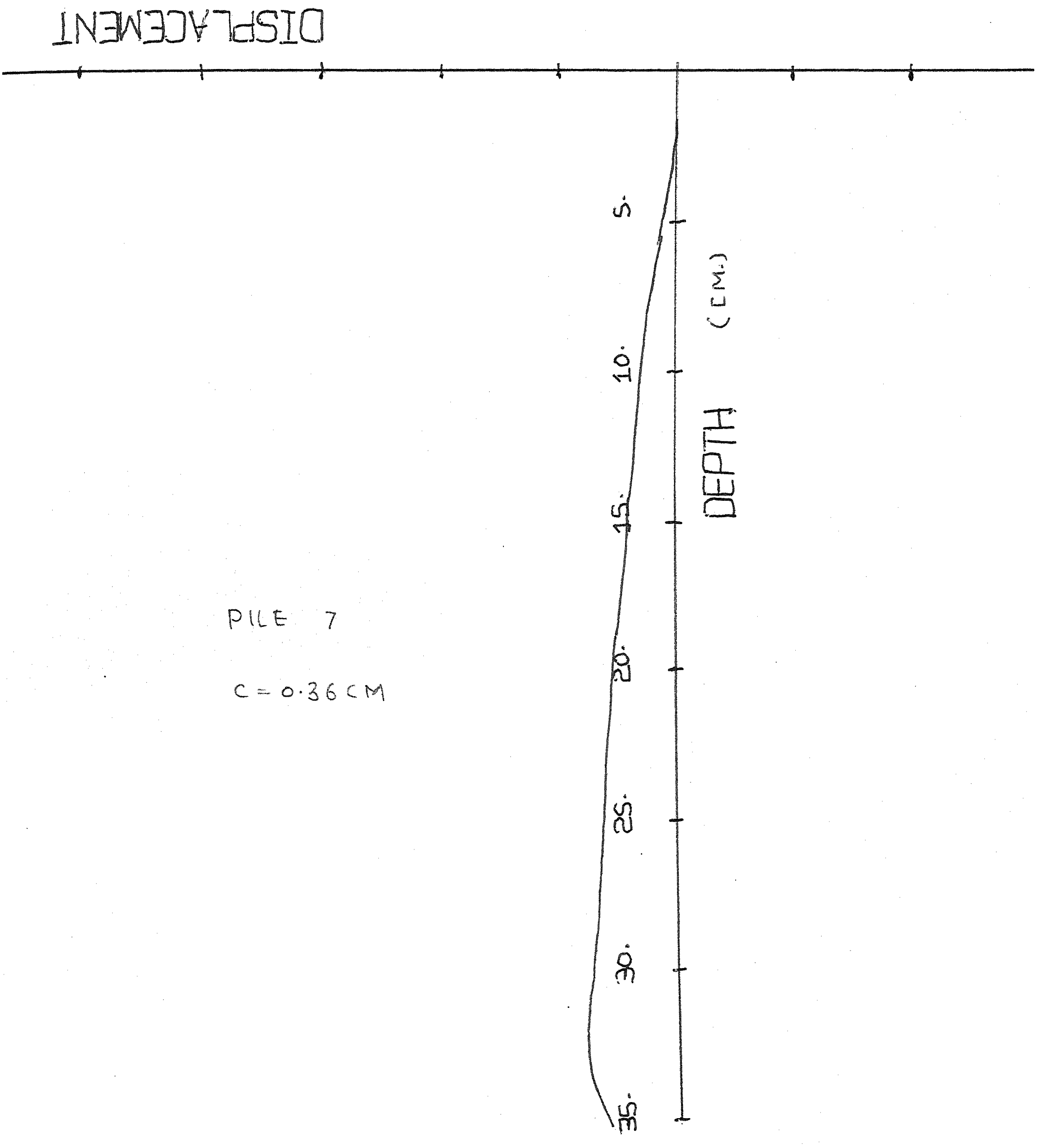

DISPLACEMENT
DEPTH
(CM.)
5.
10.
15.
20.
25.
30.
35.
PILE 4 FACE Y
c = 0.5 CM

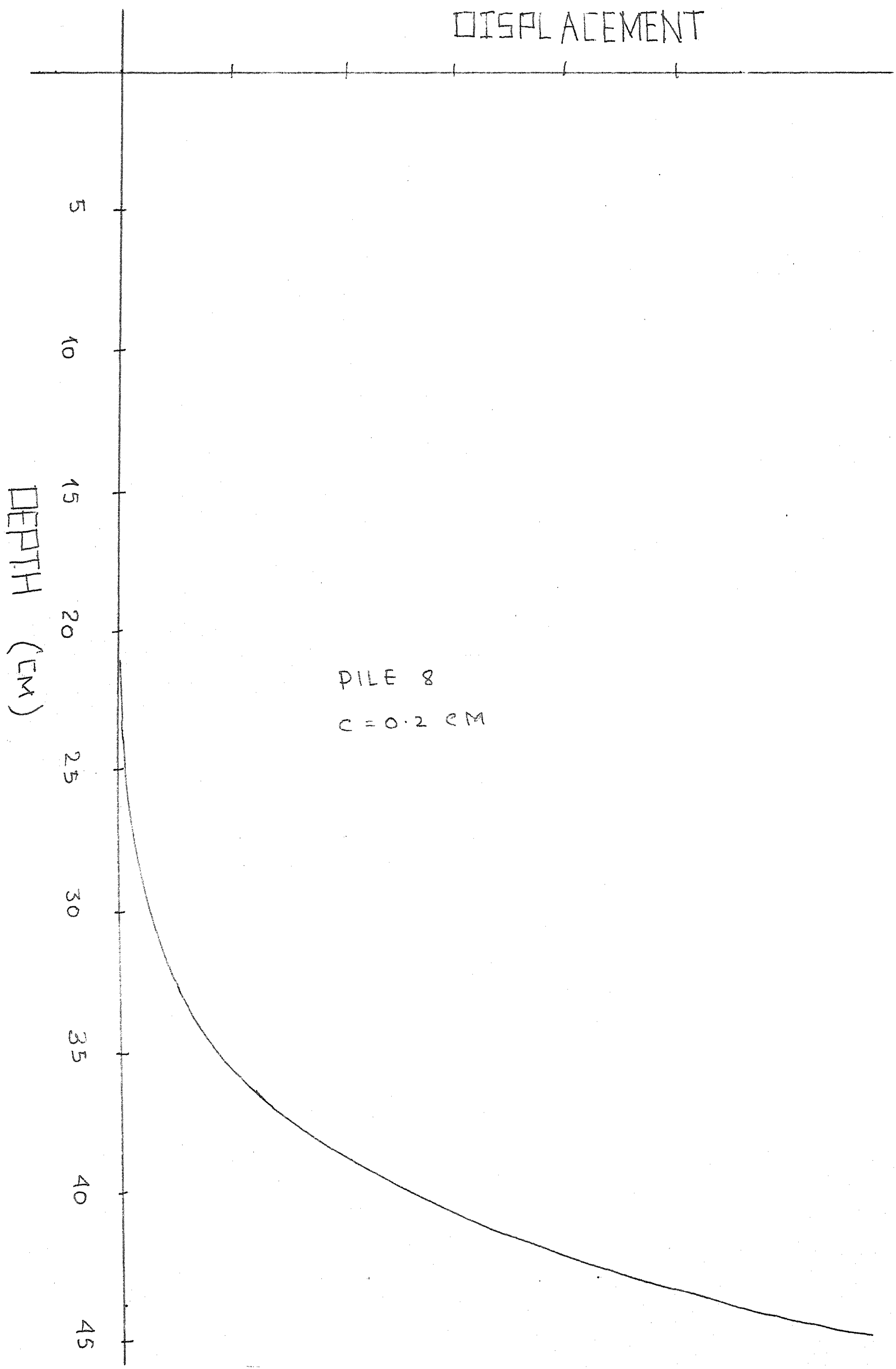

DISPLACEMENT
DEPTH
(M.)
5.
10.
15.
20.
25.
30.
35.
PILE 4 FACE X
C = 0.019 CM


DISPLACEMENT
DEPTH
5.
10.
15.
20.
25.
30.
35.
(CM)
PILE 5 FACE Y
C = 0·02 CM

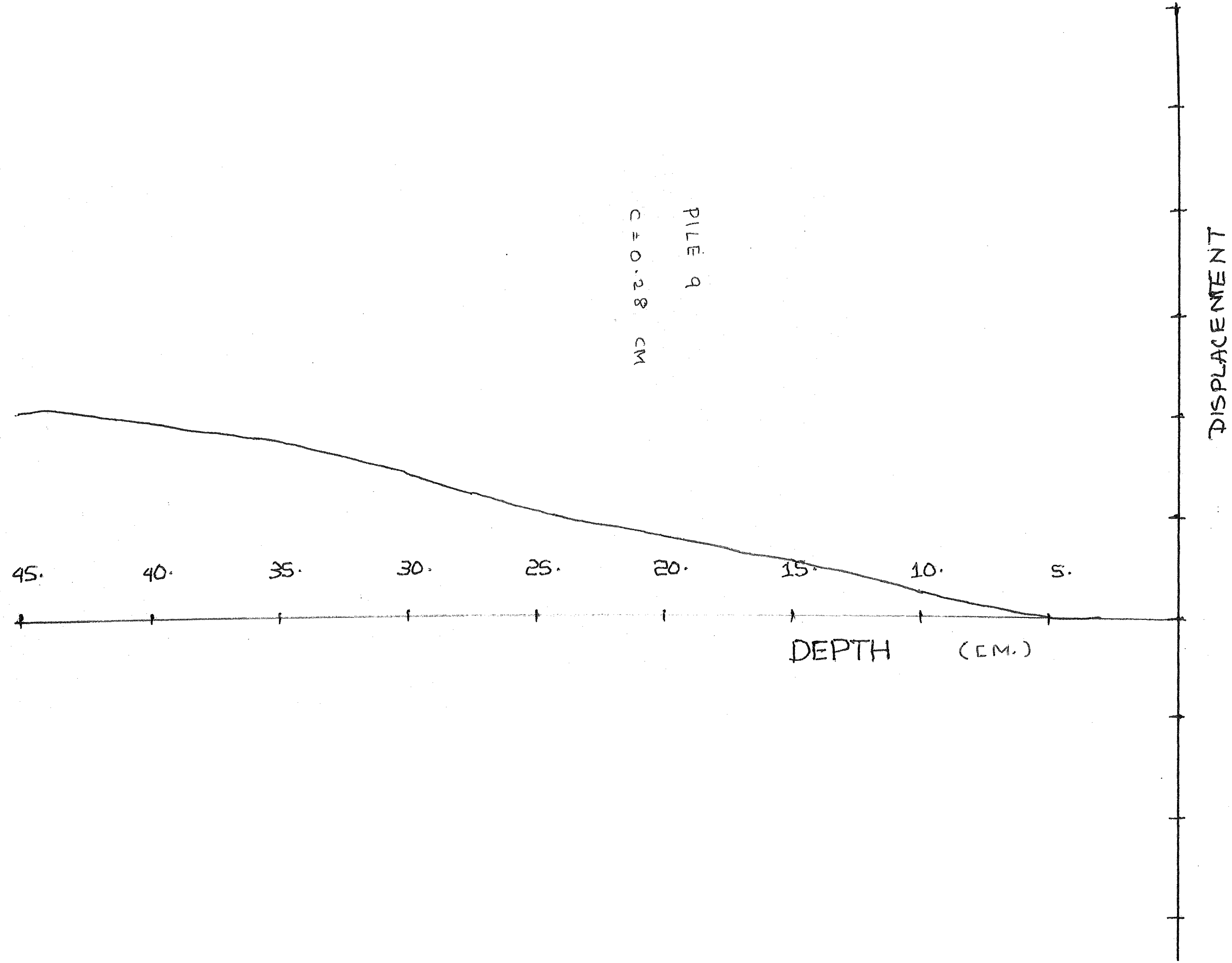

DISPLACEMENT
DEPTH (CM.)
5.
10.
15.
20.
25.
30.
35
PILE 5 FACE X
C = 0·023 CM


DISPLACEMENT
DEPTH (CM)
5.
10.
15.
20.
25.
30.
35.
PILE 6
C=0.015 CM

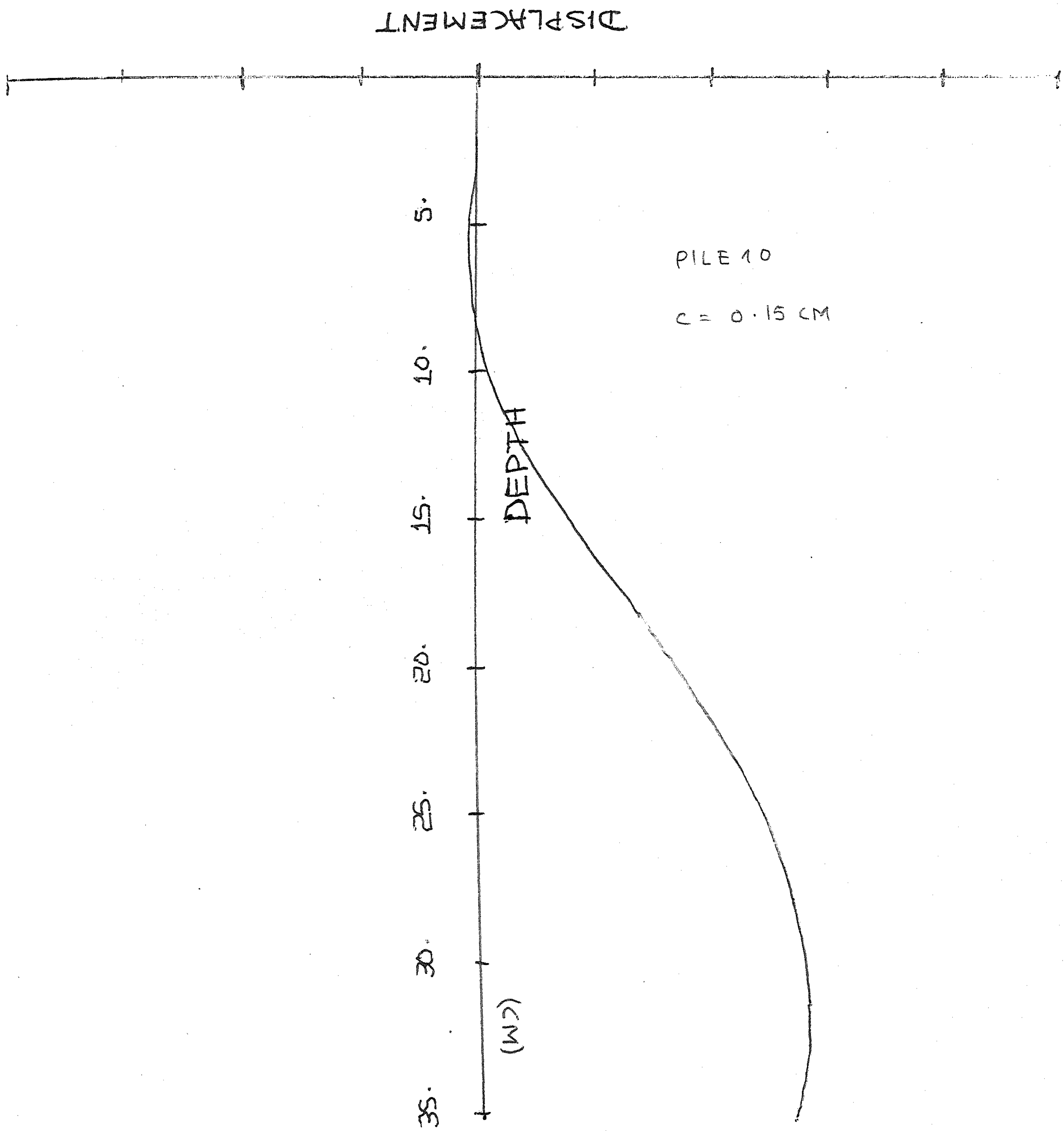

DISPLACEMENT
DEPTH (CM.)
5.
10.
15.
20.
25.
30.
35.
PILE 7
C = 0·36 CM

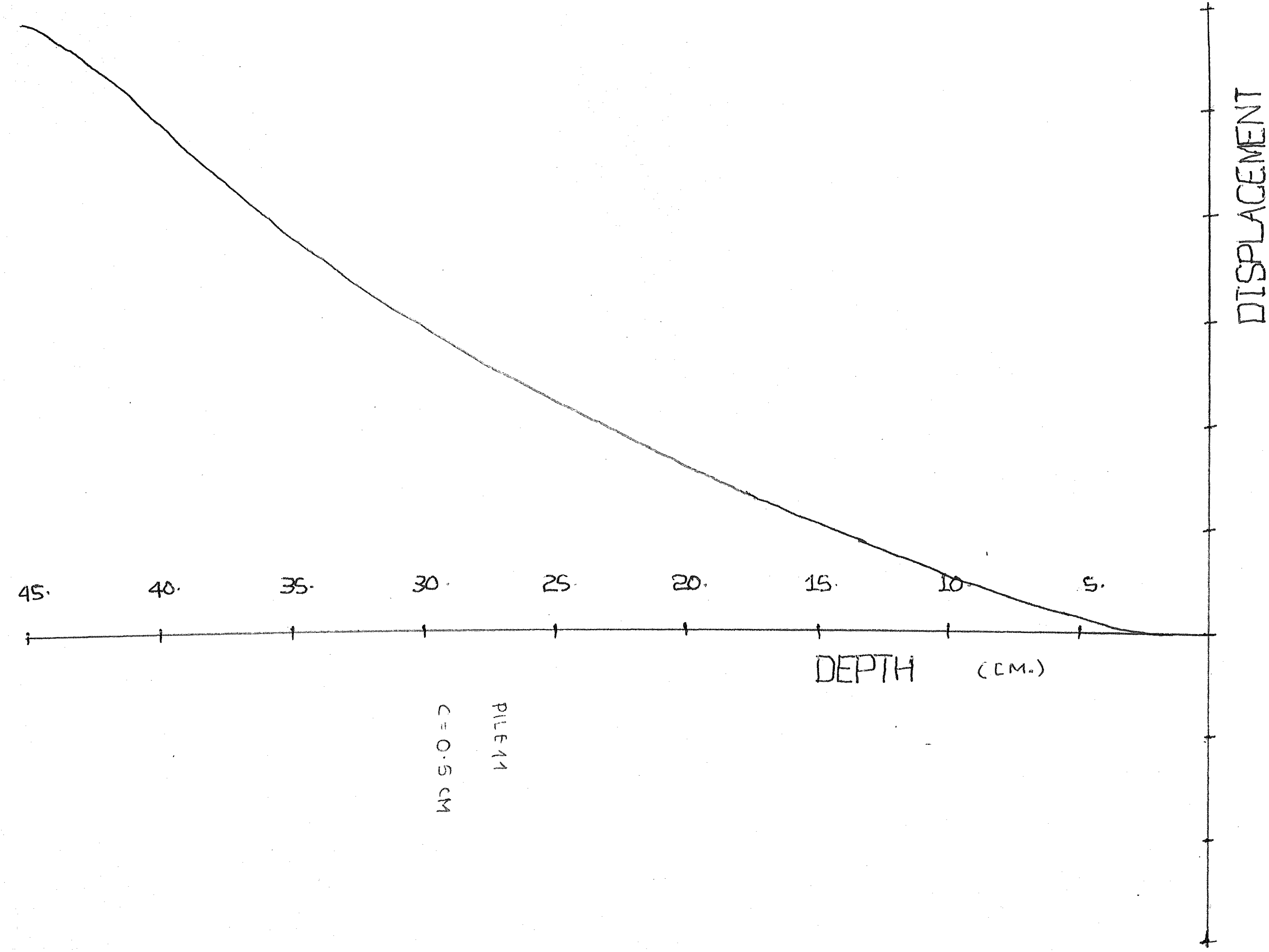


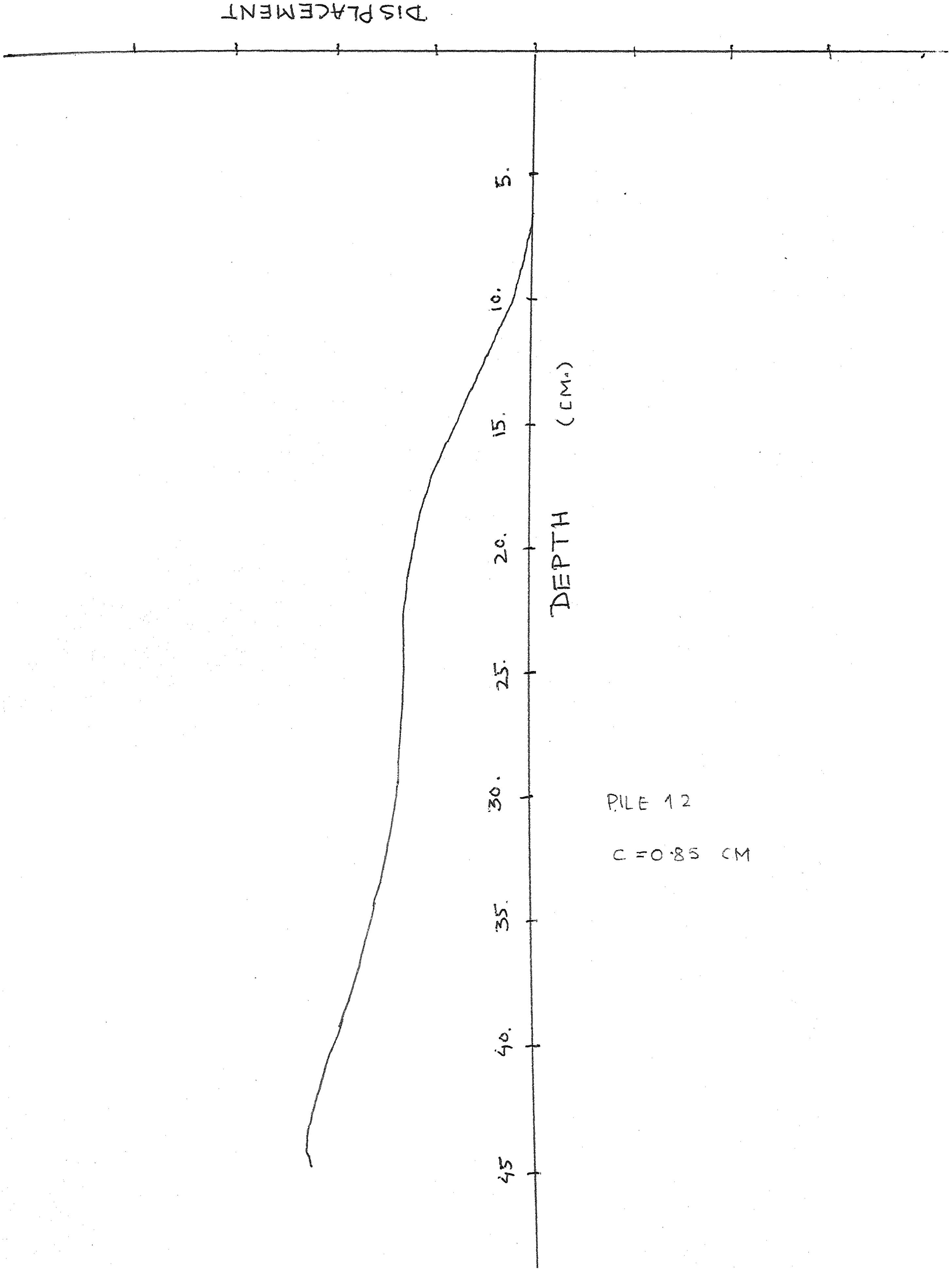
DISPLACEMENT
DEPTH (CM)
5
10
15
20
25
30
35
40
45
PILE 8
C = 0·2 CM



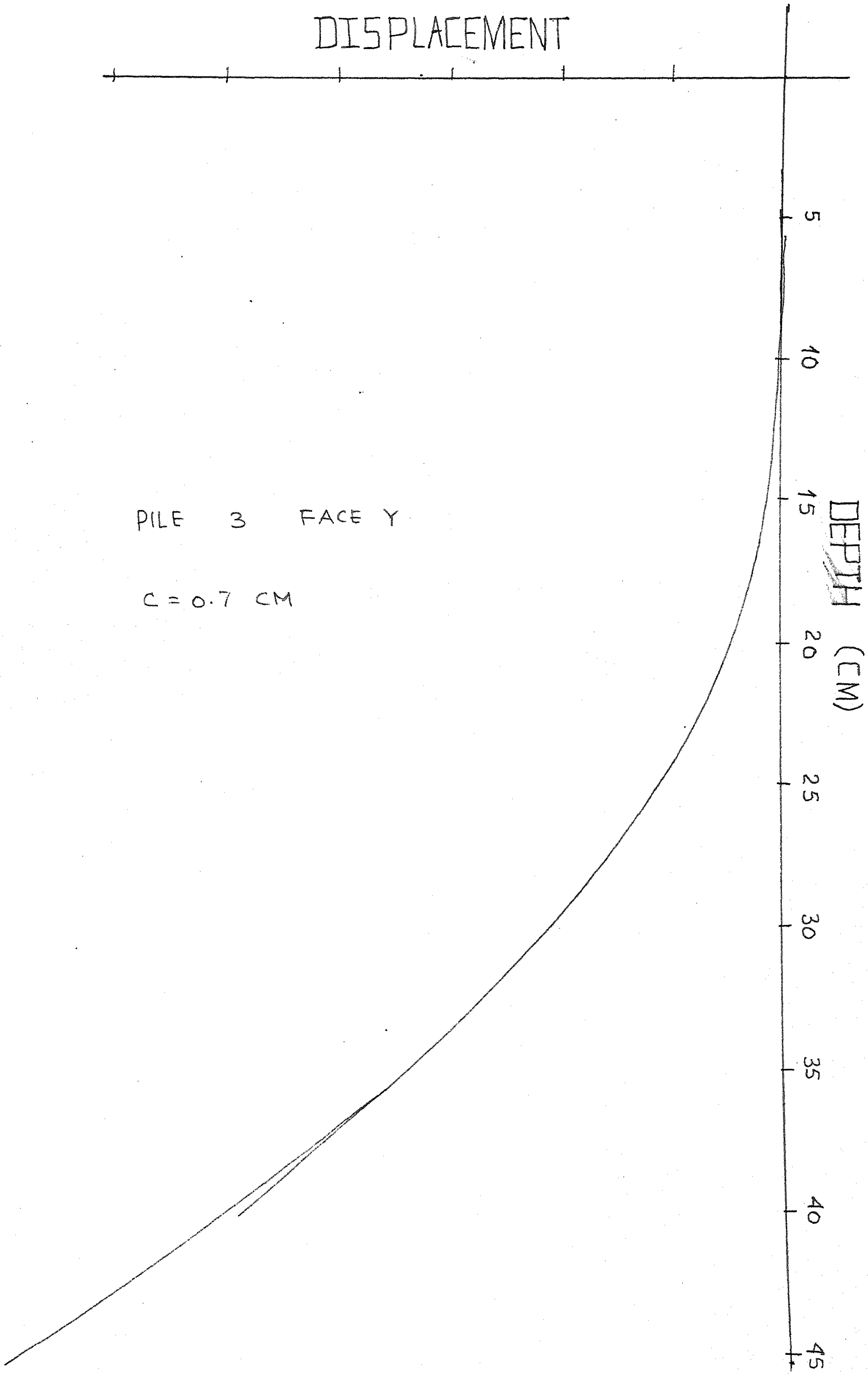
PILE 9
C = 0.28 CM
DISPLACEMENT
DEPTH (CM.)
45.
40.
35.
30.
25.
20.
15.
10.
5.

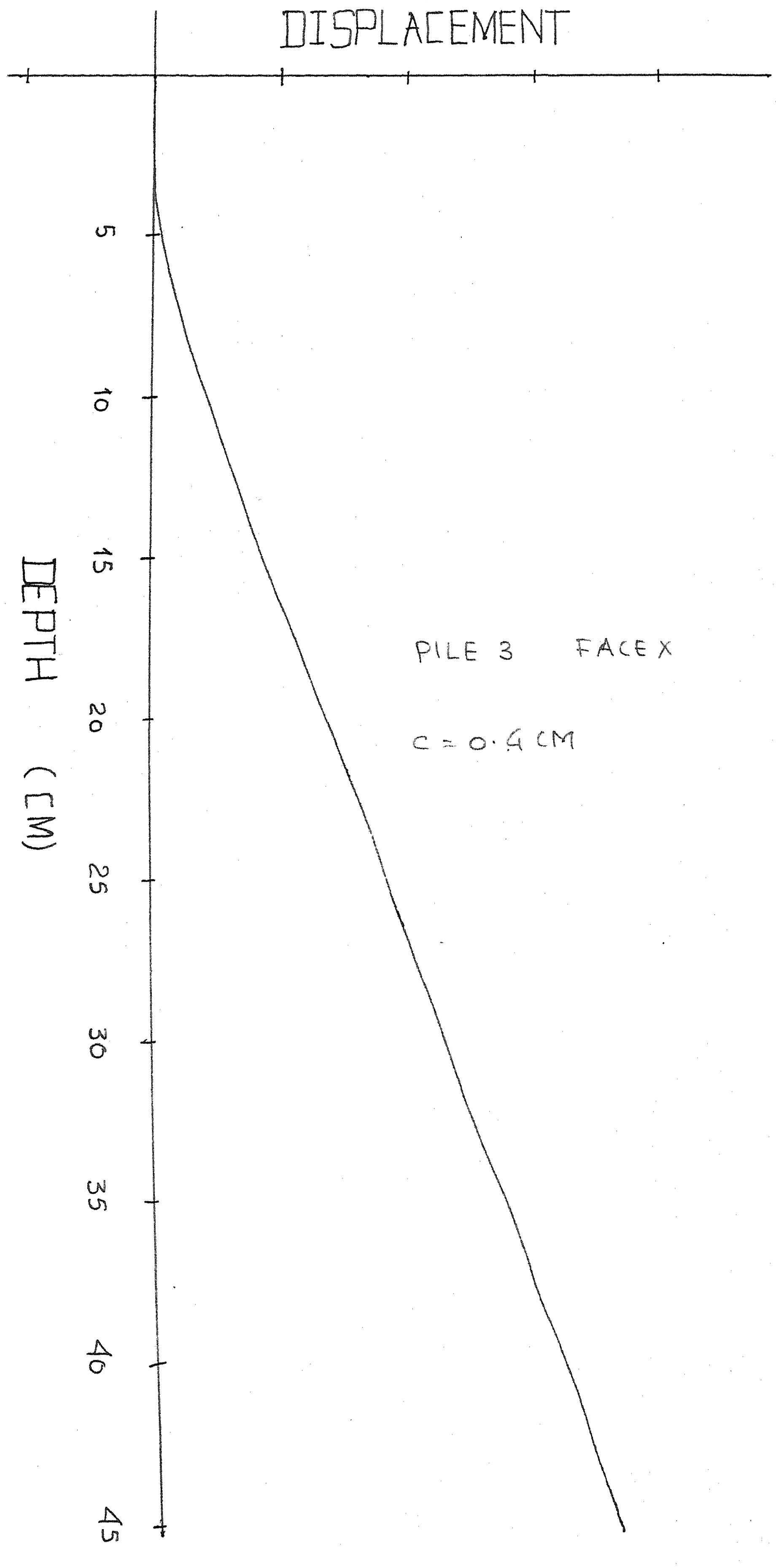

DISPLACEMENT
DEPTH
(CM)
5.
10.
15.
20.
25.
30.
35.
PILE 10
c = 0·15 CM

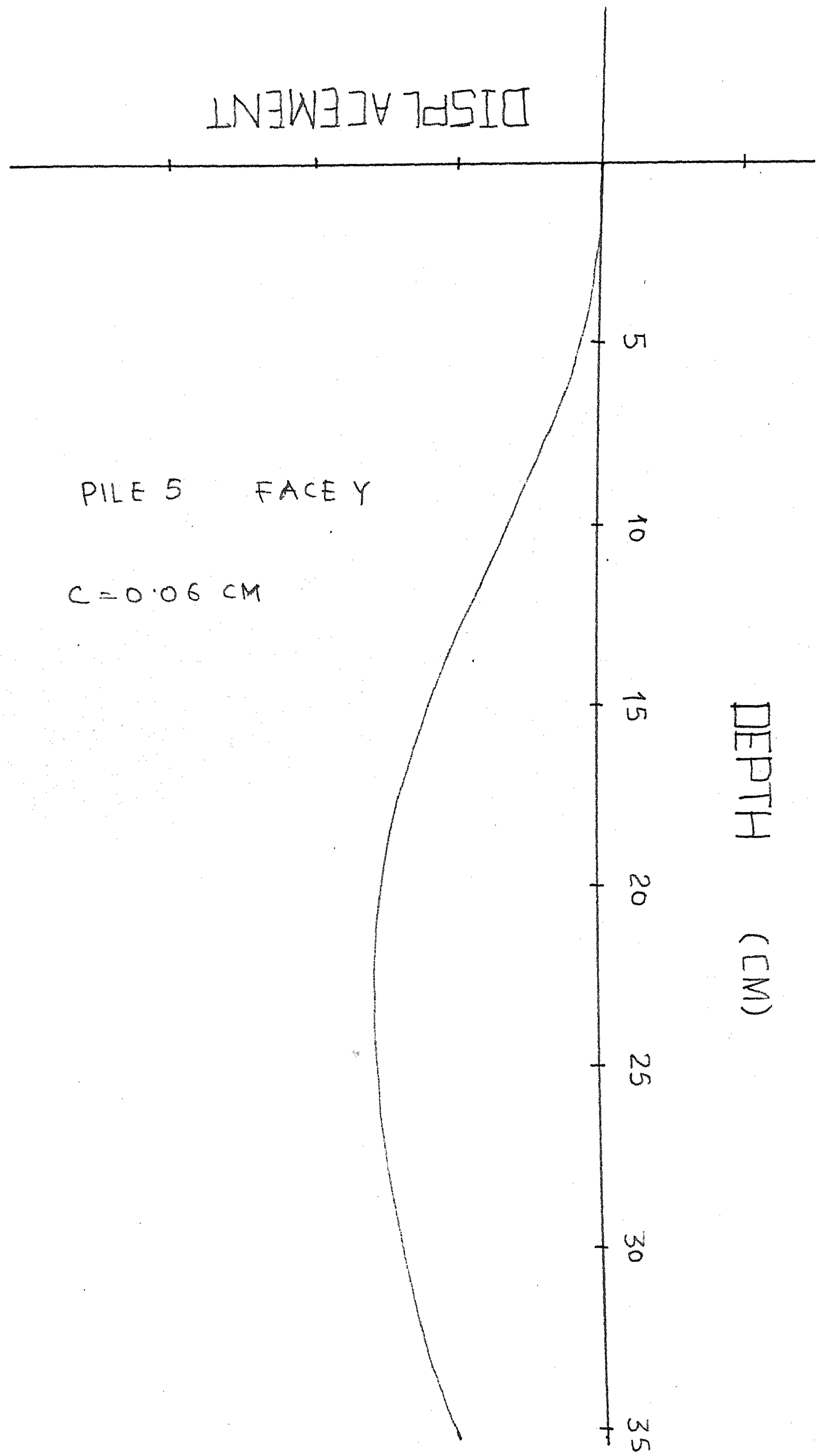

DISPLACEMENT
DEPTH (CM.)
45. 40. 35. 30. 25. 20. 15. 10. 5.
PILE 11
C = 0·5 CM


DISPLACEMENT
DEPTH (CM.)
5.
10.
15.
20.
25.
30.
35.
40.
45
PILE 12
C = 0·85 CM

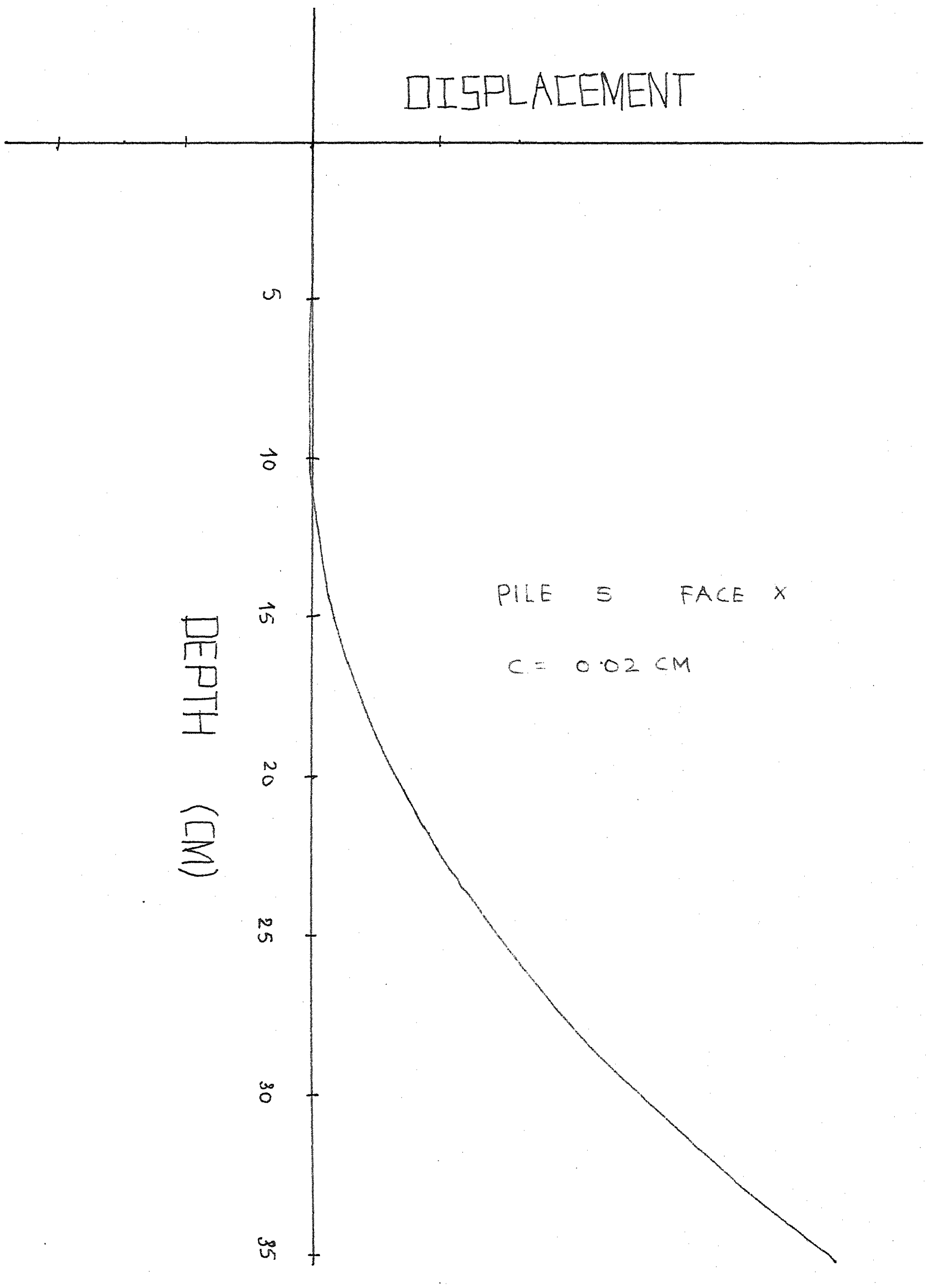
PILE SHAPE DURING AXIAL LOAD TEST


DISPLACEMENT
PILE 3 FACE Y
C = 0.7 CM
DEPTH (CM)
5
10
15
20
25
30
35
40
45

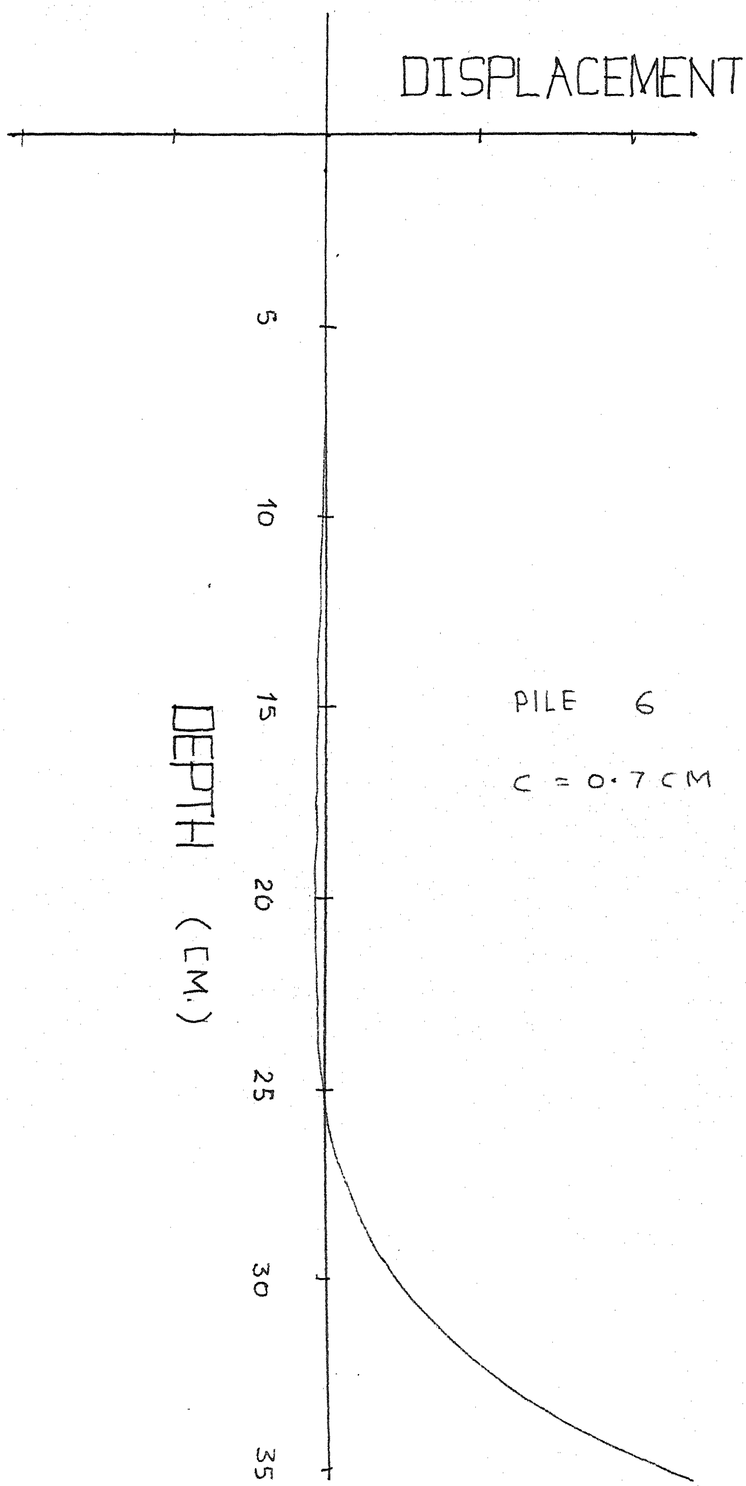

DISPLACEMENT
DEPTH (CM)
5
10
15
20
25
30
35
40
45
PILE 3 FACE X
C = 0·4 CM

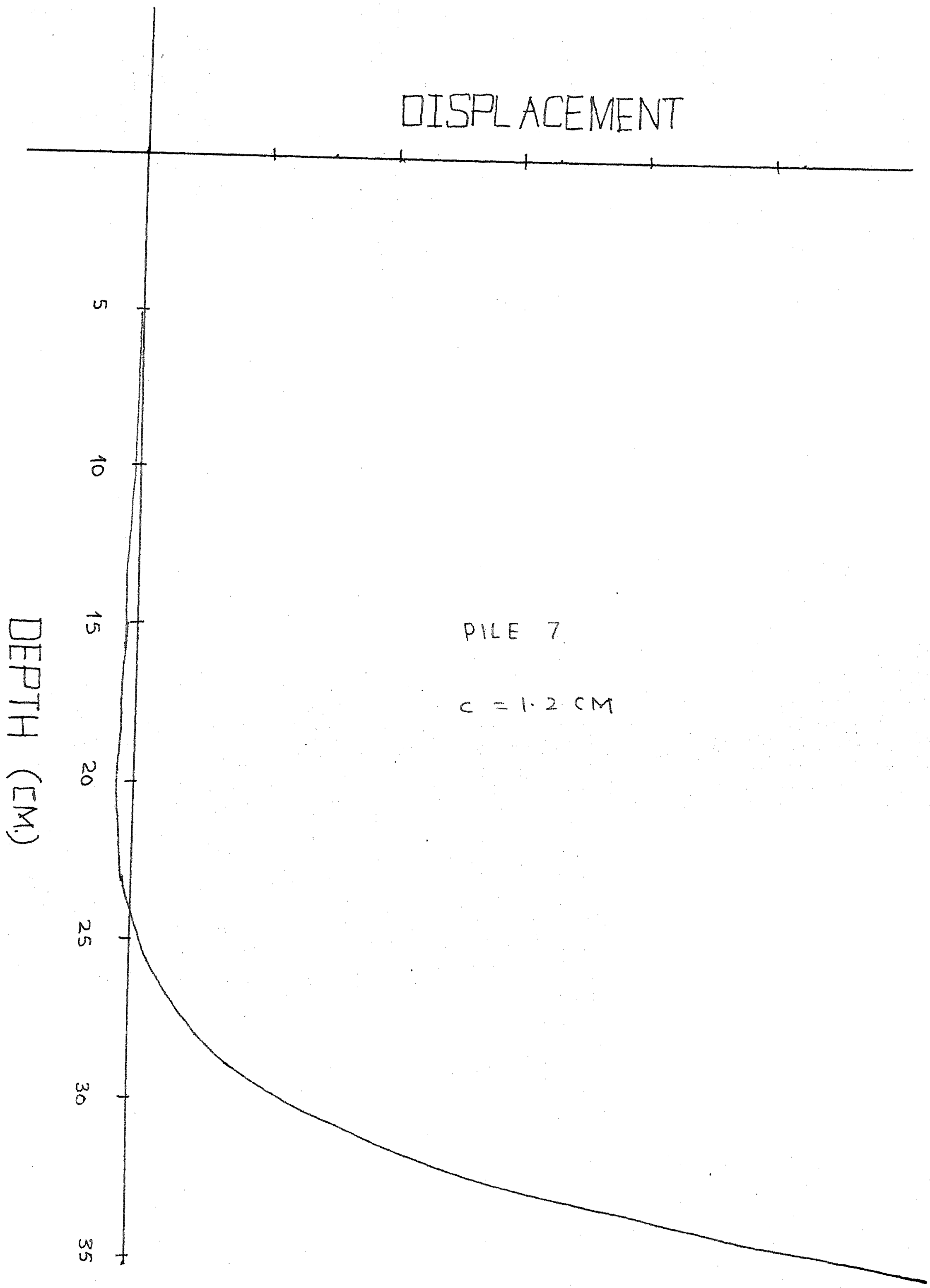


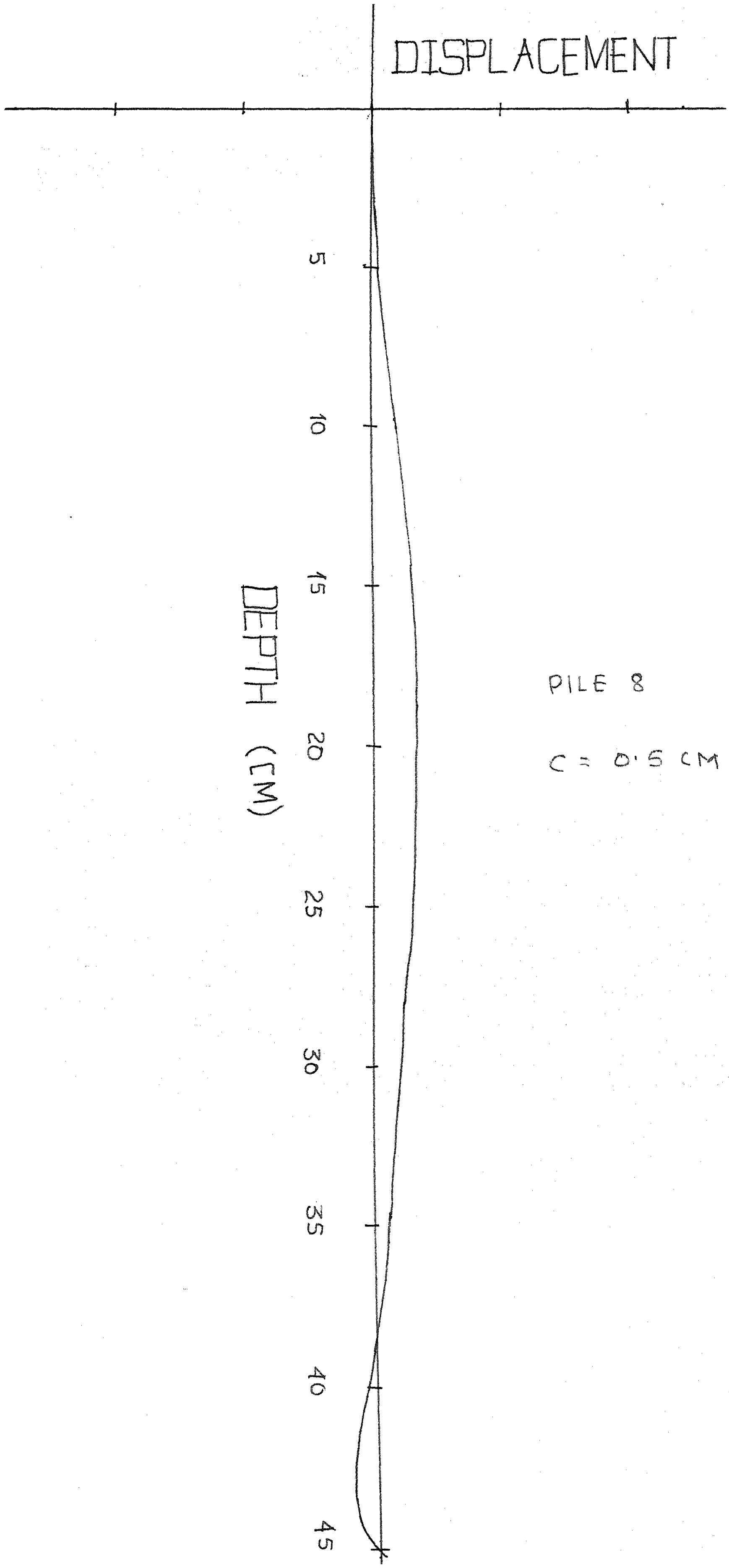
DISPLACEMENT
PILE 5 FACE Y
C = 0·06 CM
DEPTH (CM)
5
10
15
20
25
30
35

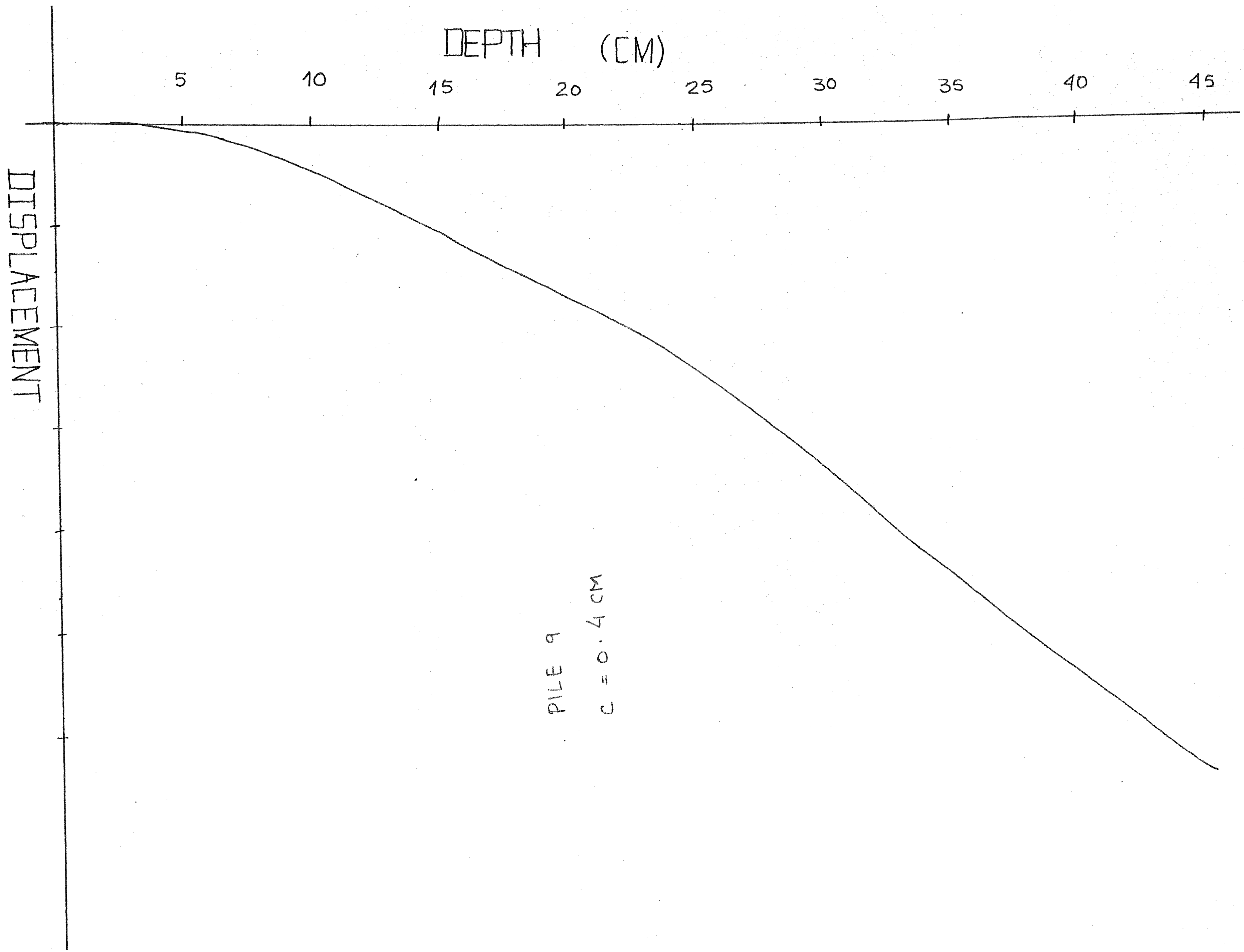


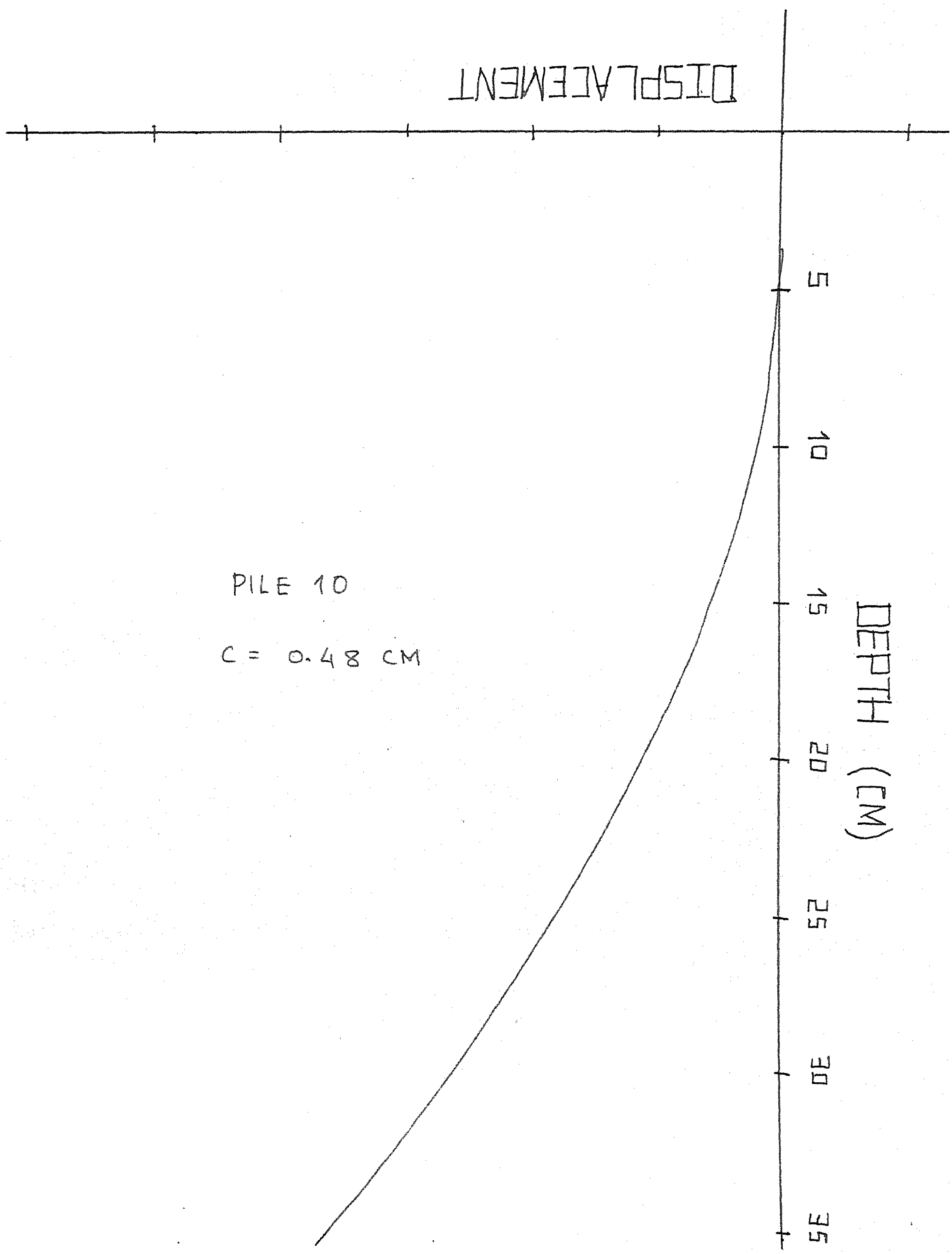
DISPLACEMENT
DEPTH (CM)
5
10
15
20
25
30
35
PILE 5 FACE X
C= 0·02 CM

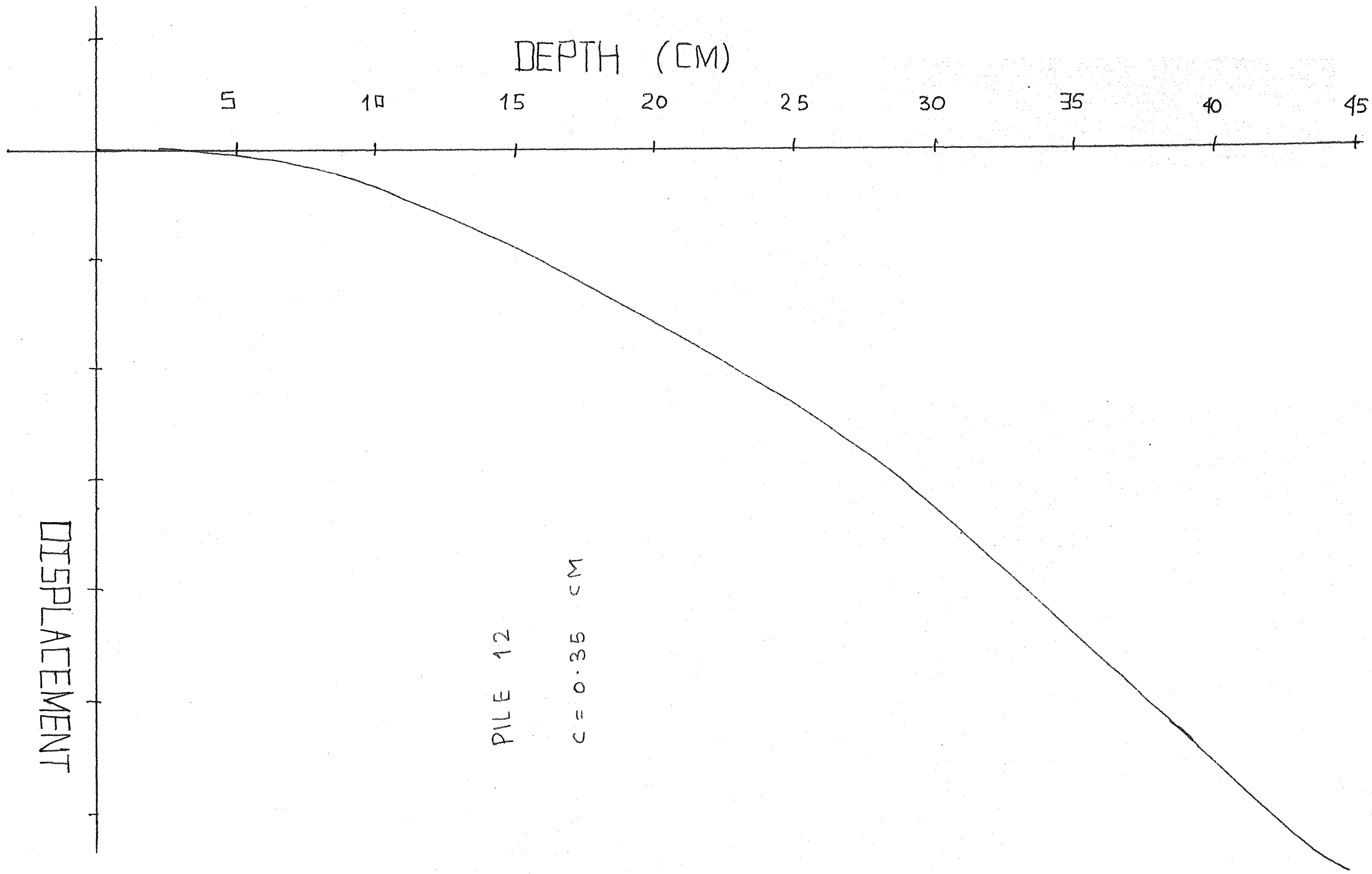

DISPLACEMENT
DEPTH (CM.)
5
10
15
20
25
30
35
PILE 6
C = 0·7 CM


DISPLACEMENT
DEPTH (CM.)
5
10
15
20
25
30
35
PILE 7
c = 1·2 CM


DISPLACEMENT
DEPTH (CM)
5
10
15
20
25
30
35
40
45
PILE 8
C = 0·5 CM


DEPTH (CM)
5
10
15
20
25
30
35
40
45
DISPLACEMENT
PILE 9
C = 0·4 CM


DISPLACEMENT
DEPTH (CM)
5
10
15
20
25
30
35
PILE 10
C = 0.48 CM



DEPTH (CM)
5
10
15
20
25
30
35
40
45
DISPLACEMENT
PILE 12
c = 0·35 cm

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